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A PRACTICAL TREATISE

ON

WARMING BUILDINGS

BY

HOT WATER;

AND

AN INQUIRY INTO THE LAWS OF RADIANT AND CONDUCTED HEAT.

TO WHICH ARE ADDED,

REMARKS ON VENTILATION,

AND ON THE

VARIOUS METHODS OF DISTRIBUTING ARTIFICIAL HEAT, AND THEIR EFFECTS ON ANIMAL AND VEGETABLE PHYSIOLOGY.

BY

CHARLES HOOD, F.R.A.S.

ILLUSTRATED BY NUMEROUS WOOD-CUTS.

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PREFACE.

A NATURAL inclination for philosophical inquiries, first led me to investigate the principles of the invention for heating buildings by the circulation of hot water; and the many favourable opportunities that have occurred for proving the accuracy of my theoretical views, have encouraged me to persevere in the investigation.

Frequent applications having been made to me, by persons who were aware that the subject had engaged my attention, to recommend to them a practical treatise on its principles and application, the utility of such a work, in forwarding the progress of the discovery, became obvious. And finding that nothing relating to the invention had hitherto been published, except a few scattered and unimportant notices, it appeared probable that the materials I possessed might form a treatise which would be

useful, not only in showing the practical application of the invention, but also in explaining the scientific principles upon which the various effects depend. The following pages are therefore offered, in the hope of supplying the desideratum.

The different parts of the subject have been arranged, as far as possible, under distinct heads. The primary object has been to explain the principles, in a manner perfectly clear and intelligible to such as are unacquainted with those branches of physical science on which the philosophy of the invention is based: and, while endeavouring to remove the erroneous notion, which is entertained by some persons, that a certain degree of danger is inseparable from the plan, to show that danger can occur only through a misapplication of the principles.

In order to pursue the inquiry in a popular manner, all abstruse calculations and scientific technicalities have been, as much as possible, avoided; and the most simple definitions the subject would admit of have been adopted, as far as is consistent with perspicuity.

The Rules, Calculations, and Tables, which are given in the body of the work, have, nearly all, been constructed expressly with reference to the present inquiry; and the Tables given at the end of the volume are compiled from the best authorities: the whole comprising, it is hoped, all the information which the subject requires.

In extenuation of any omissions or errors which may be found, it should be borne in mind that, hitherto, no attempt has been made to give a comprehensive view of this invention. The increasing attention of the public to the subject, however, renders the present time the most proper for the publication of such a treatise as the one now offered: and though probably much remains to be discovered relating to the invention, the communication of what is already known is the surer way of extending the sphere of its utility, than by waiting until its principles shall be more fully revealed by time, in the hope of producing a more complete work. But although no excuse is thus intended to be offered for any errors, other than such as are trivial and unimportant, if any omissions be found, the plea may be urged, and will, perhaps, be admitted—*Bis dat qui citò dat.*

To conclude these prefatory remarks: it may be observed that in pointing out, and freely commenting on the erroneous principles which have, in some instances, been both theoretically and practically promulgated by others, it is under the impression that such errors, carrying with them in general considerable plausibility, might, if unconfuted, lead not only to inconvenience, but even to danger; more particularly, as, on account of their emanating from men of ability, others may also be liable to fall into similar mistakes. However invi-

dious, therefore, the task of pointing out such errors may seem, it appeared to be necessary, when writing on this subject, not only to exhibit what were considered to be the true principles, but also to show where erroneous notions have been adopted. This must be the apology for the freedom with which the opinions and inventions of others are descanted on in the following pages; and, as these are not the production of an inventor, who is expatiating on the advantages of his own particular plan, they will, it is hoped, be found a candid inquiry into the merits of the various descriptions of apparatus which are brought under consideration, pointing out their philosophical principles, and displaying their utility in a practical manner.

C. H.

Earl Street, Blackfriars,
September, 1837.

CONTENTS.

CHAPTER VIII.

CHAPTER IX.

CHAPTER X.

CHAPTER XI.

CHAPTER XII.

ERRATA.

Page 35, line 2 of note, *for* " also *directly*," *read* " the friction *directly*."
— 89, — 11, *for* " (a^t-1)" *read* " (a^t-1)."

A

PRACTICAL TREATISE,

&c.

INTRODUCTION.

THE practice of employing hot water, circulating through iron pipes, for diffusing artificial heat, has now become so general, that its merits are acknowledged as an invention of utility. The last twelve years, though they have not actually been witness to the discovery of the plan, have, at least, revealed nearly all that is known respecting its practical application; for, previously, the range of its operation was confined rather to a few cases of experiment, than extended to any general or useful purposes.

It can scarcely excite surprise, that prejudices should formerly have existed against this invention, while its merits and its principles were alike imperfectly known. Even at the present time they are

but partially understood; and, therefore, to investigate these two subjects, is the proposed object of the present treatise, with the view of facilitating its application, and extending the sphere of its utility.

There is scarcely any branch of science or of art, in which an acquaintance with the laws of Nature does not enable us to derive greater advantages in its application, than we could otherwise possess. Although it is true that we are still ignorant of the more subtile agents which exist in the vast chain of causation, the laws which regulate the various phenomena of nature, are sufficiently known to afford the most beneficial assistance to every branch of the arts and sciences: and the most recondite of scientific discoveries, as well as the most valuable inventions and improvements in the arts, are not more demonstrative of the truth of this assertion, than are those of the most simple characters.

For an illustration of the utility of this knowledge, we may refer to the law of gravity; not only because it is, of all natural phenomena, the most constant in its operation, and the most universal in extent, but because its influence is closely connected with the present subject of inquiry.

That all falling bodies gravitate with the same velocity, and, therefore, descend through a certain definite space in a given time, is, we know, an effect

of which gravity is the *cause*. It is on the operation of this invariable law, that many of our most valuable inventions depend. Its influence is equally exerted on all objects; as well the most dissimilar, as the most alike; as well the most mighty, as the most minute. It is from this cause that we obtain the unerring action of our pendulums and clocks; and it is by this also we obtain the circulation of hot-water, with which we warm our dwellings. But by a knowledge of the cause of these effects, of the extent of its operation, and of the laws by which it acts, we can, by varying the circumstances of a gravitating body, alter also the velocity of its descent. And we accomplish this by bringing other causes into operation, which modify the result, notwithstanding the immutability of the laws of gravity. Thus, we can modify and subject to our will, one of the most constant and universal agents in Nature, by a knowledge of the physical laws.

The study of the laws which govern natural phenomena,—which in all cases are so simple, so beautiful, so perfect,—is, therefore, one of the most fruitful sources of inquiry which the mechanician can pursue. Without it all his plans will either be modified copies of existing inventions, or they will degenerate into wild speculations, unsupported on any reasonable foundation.

This is particularly observable in the case before us. The numerous failures which have occurred

in the practical application of the invention of heating buildings by the circulation of hot water, are all distinctly referrible to the want of this kind of knowledge, and not to the object aimed at being itself unattainable. But whenever the physical laws are intended to be employed as the principal agents in producing any mechanical effect, it is an indispensable condition that simplicity of action be kept in view. While it may further be observed, that the endeavours to trace and elucidate the operating causes of the various phenomena, which occur in the course of practical experiments, are the surest means of facilitating original discoveries, as well as of promoting new adaptations of recognised principles.

The origin of the invention of employing hot water for diffusing artificial heat, appears to be hid in considerable obscurity. It is not improbable that, similar to many other discoveries, it has been evolved at various periods from the Alembic of Time. It seems, in one instance at least, to have been used in France about sixty years since. After fading from recollection for a space of about forty years, it appears to have been re-invented by the Marquis de Chabannes, and subsequently by Mr. Bacon and Mr. Atkinson. And it was the latter, who, undoubtedly, first gave to the apparatus the arrangement, under which it is now generally used in its most simple form.

The variations since made in its more complicated arrangements, appear to have been very gradually adopted. Each time that an apparatus has been erected, the experimentalist has deviated in some small degree from the model of that which preceded; apparently afraid of venturing on too great a variation, yet requiring, from contingent circumstances, some alteration of its form and application. This mode of proceeding, though natural while the principles were not thoroughly understood, has frequently led to both inconvenience and loss, in consequence of the numerous failures to which it has given rise, by unintentional deviations from the principles. In the present attempt to elucidate the subject, it will however be shown, that success needs not be uncertain, provided only, that the laws of physics be justly applied and strictly adhered to.

Neither the capabilities of this method of warming, nor the various useful purposes to which it is applicable, are at present fully appreciated. There are no buildings, however large, to which it cannot be advantageously adapted, nor any that present insurmountable difficulties in its practical application. It is an invention only yet in its infancy, but which gives promise of a maturity that will confer the greatest advantages where its employment is the most extensive.

Its merits, however, will best appear by the

plainest statements of facts. We shall proceed, therefore, at once, to the main object which has been proposed; an investigation of the *principles* of this invention, as applied to the warming of buildings.

CHAPTER I.

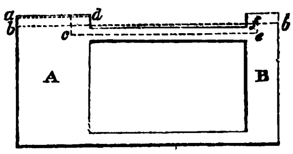
Cause of Circulation of the Water—Force of Gravity—Pressure of Water—Effect produced on the Circulation by increased Height of the Pipe.

Art. 1. In endeavouring to explain the principles of the various forms of apparatus in which hot water, circulating through iron pipes, is employed as a means for distributing artificial heat, the first object should be to point out, as clearly as possible, the power which produces circulation of the water; for without a clear perception of this part of the subject, there will always be an uncertainty as to the results which will obtain, when any departure is made from the most simple form and arrangement of the different parts of the apparatus. It is this circulation which causes all the water in the apparatus to pass successively through the boiler, and then communicates the heat that is thus received from the fuel, to the various buildings or apartments which it is designed to warm. Without this circulation, those parts of the apparatus which are remote from the fire would not receive any heat;

because water is so bad a conductor, that it is only when there exists perfect freedom of motion among its particles, that it acts at all as a conductor of heat, so far, at least, as regards any practical and useful effect. It is in a complete and perfect circulation, therefore, that the efficiency of a hot water apparatus depends, and that the greatest amount of heat is obtained by it from a given quantity of fuel.

2. The only treatise hitherto published, in which any attempt has been made to explain the cause of circulation of the water in this description of apparatus, is Mr. Tredgold's work on heating by steam; and the effect is there referred entirely to an erroneous cause. In the Appendix to that work, the cause of motion is thus explained. "If the vessels A, B, and pipes, be filled with water, and heat be applied to the vessel A the effect of heat will expand the water in the vessel A, and the surface will, in consequence, rise to a higher level *a, d*, the former general level surface being *b, b*. The density of the fluid in the vessel A will also decrease in consequence of its expansion; but as soon as the column *c, d* (above the centre of the upper pipe) is of a greater weight than the column *f, e*, motion will commence along the upper pipe from A to B, and the change this

FIG. 1.

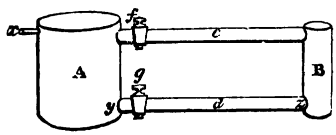


motion produces in the equilibrium of the fluid, will cause a corresponding motion in the lower pipe from B to A."

3. Now it is certain that this theory will not account for the circulation of the water, under all circumstances, and every variety of form, of the apparatus; and as the cause of motion must be the same in all cases, any explanation which will not apply universally must necessarily be erroneous. Were this the true cause of motion, there would be no difficulty in obtaining a circulation in all cases; for, according to this reasoning, whenever the level of the water is higher in the boiler than in the pipes—or even if an upright pipe were placed on the top of a close boiler, by which the pressure on the surface would be increased,—the water must, of necessity, circulate through the pipes. On the other hand, if this hypothesis were correct, the water in an apparatus, constructed as in the following figure, would not circulate at all.

4. Suppose the apparatus fig. 2, to be filled with cold water, and the two stop-cocks *f*, *g*, to be closed: on applying heat to the vessel A, the water it contains will expand in bulk, and a part of it

Fig. 2.



will flow through the small waste pipe *x*, which is so placed as to prevent the water rising higher in the vessel A, than the top of the vessel B. The water

which remains in the vessel A, after it has been heated, and a portion of it has passed through the waste-pipe *x*, will evidently be lighter than it was before, while its height will remain unaltered. Suppose, now, the two cocks *f*, *g*, to be simultaneously opened; the hot water in the boiler A will immediately flow towards B through the upper pipe, and the cold water in B will flow into A through the lower pipe; although, by the above mentioned hypothesis, unless the water in the vessel A, above the pipe *c*, were heavier, or rose to a higher level than the water in the vessel B, no circulation could take place. In this case, therefore, we must find another explanation of the cause of motion.

5. The power which produces circulation of the water, will be found to arise in a different manner to what is here stated; for we see that this reason is insufficient to account for the effect, even in one of the simplest forms of the apparatus.

6. In order to explain this, let us suppose heat to be applied to the boiler A, fig. 2. A dilatation of the volume of the water takes place, and it becomes lighter; the heated particles rising upwards through the colder ones, which sink to the bottom by their greater specific gravity, and they in their turn become heated and expanded like the others. This intestine motion continues until all the particles become equally heated, and have received as much heat as the fuel can impart to them. But as soon

as the water in the boiler begins thus to acquire heat, and to become lighter than that which is in the opposite vessel B, the water in the lower horizontal pipe *d*, is pressed by a greater weight at *z* than at *y*, and it therefore moves towards A with a velocity and force equal to the difference in pressure at the two points *y* and *z*[1]. The water in the upper part of the vessel B would now assume a lower level, were it not that the pipe *c* furnishes a fresh supply of water from the boiler to replenish the deficiency. By means of this unequal pressure on the *lower* pipe, the water is forced to circulate through the apparatus, and it continues to do so as long as the water in B is colder, and therefore heavier, than that which is in the boiler; and as the water in the pipes is constantly parting with its heat, both by radiation and conduction, while that in the boiler is as continually receiving additional heat from the fire, an equality of temperature never can occur; or else if it did, the circulation would cease.

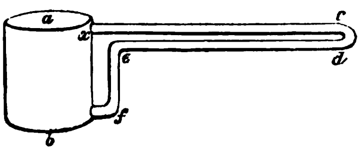
(7.) We see, then, that the cause of the circula-

[1] To any person unacquainted with the science of Hydrostatics, this may probably appear erroneous; because the quantity of water contained in A is much greater than that in B. It is, however, one of the first laws of Hydrostatics, that the pressure of fluids depends for its amount on the height of the fluid only, and is wholly irrespective of the bulk, or actual quantity of fluid: therefore, a pipe which is not larger than a quill, will transmit the same amount of pressure, as though it were a foot, or a yard, in diameter, provided the height be alike in both cases. (See Art. 16.)

tion is the unequal pressure on the lower pipe of the apparatus; and that it is not the result of an alteration which takes place in the level of the water, as has been erroneously supposed. Indeed, the truth of this appears so plain, that it would scarcely require explanation at such a length, were it not that false opinions in this matter appear to have led to many errors in practice.

(8.) As the circulation is caused by the water in the descending pipe being heavier than that which is in the boiler; it follows, as a necessary consequence, that the colder the water in the descending pipe shall be, relatively to that which is in the boiler, so much the more rapid will be its motion through the pipes. In such an arrangement of pipes as fig. 3, the water in the descending pipe *e f*, having to travel farther before it descends to the lower part of the boiler, than when the pipes are arranged as in fig. 2, it will of course be colder at the time of its descent, in the case, fig. 3, than in fig. 2, and therefore the circulation will be more rapid. The height of the descending pipe is supposed to be alike in both cases; because *c d* and *e f*, are, together, equal to *a b*.

Fig 3.



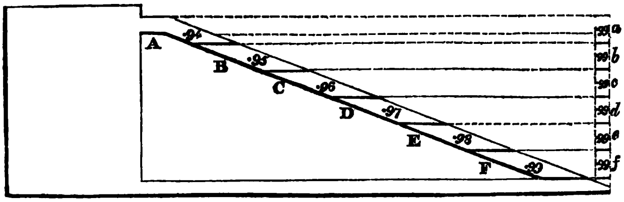
(9.) Some persons have imagined that if the pipes be inclined, so as to allow a gradual fall of the water

in its return to the boiler, additional power is gained; as, for instance, by inclining the lower pipe of fig. 3, so as to make the part *e* lower than *d*, and then reducing the vertical height of the return pipe *e f*. This, at first, appears very plausible, particularly with regard to some particular forms of the apparatus; but the principle is, in fact, entirely erroneous. The author of the Appendix to Tredgold's work, already quoted, in consequence of adopting the erroneous hypothesis, that the motion of the water commences in the upper pipe instead of the lower one, as already described, appears to recommend an inclination being given to the pipes in this manner; and he has described an apparatus that he erected, to which a fall of four feet was given to the water in this manner.

This error appears to arise from treating the subject as a simple question of hydraulics, instead of a compound result of hydrodynamics. But in order to ascertain what is the effect of thus inclining the pipes, let us suppose an extreme case.

(10.) It is evident that the farther the water flows, the colder does it become. It must therefore be hotter at A (fig. 4) than it is at B, and hotter at

Fig. 4.



B than C, and so on. Let us, now, suppose any arbitrary number to represent the specific gravity of the water at A; say, for instance, ·94. The water at B, in consequence of having flowed farther and therefore become colder and heavier, will be, we will suppose, of the specific gravity of ·95; at C, for the same reasons, it will be ·96, and so on to F, where, from having run the greatest distance from the boiler, it will be the heaviest of all[1]; and the sum of all these numbers represents the pressure at F. But had the pipe, instead of inclining gradually from the boiler, continued on a level to *a*, as represented by the dotted lines, the water would have been as cold, and therefore as heavy, at *a*, as, by the former arrangement, it is at F, and therefore its specific gravity would be the same, namely, ·99. Now, as the pressure of water is as its vertical height, by dividing the vertical pipe, *a*, *f*, in the same manner as we have done with the inclined pipe, we shall have *a*, *b*, *c*, *d*, *e*, *f*, each equal in altitude to the corresponding divisions of the inclined pipe; and as the specific gravity of each division is equal to ·99, the total number representing the sum of all these, will show the pressure at the point *f*. We shall hence find the pressure of the vertical pipe

[1] The real specific gravities could not conveniently be used in this illustration, as they would require several decimal places of figures. See Table IV.

compared to the inclined pipe, will be as 5·94 is to 5·79[1].

(11.) It is therefore evident there must be a considerable loss on the effective pressure, by making the pipe to incline below the horizontal level. Nor can this loss be compensated in any manner; for the total height being the same, whether the water descends through a vertical or through an inclined pipe, the force of gravity will only be equal to the *mass* of matter. And as there is actually more matter in a pipe filled with cold water than in a similar pipe filled with hot water, the gravitating force will be inversely proportional to the temperature; that is, it will be less in proportion as the temperature of the water is greater. There must therefore, under all circumstances, be a positive loss of effect by inclining the pipe in the manner stated[2].

(12.) In such a form of apparatus as fig. 3, there would be no circulation of the water, unless some plan were adopted by which the air would be dis-

[1] If the strict analogy were carried out, the difference ought to be greater than is here represented; because it is evident that instead of *a*, *b*, *c*, *d*, etc., being each of equal density, *b* will be heavier than *a*, and *c* heavier than *b*, and so on; but the illustration, as now given, will be sufficient to show the principle.

[2] It must not be supposed that this reasoning at all applies to any case of pure hydraulics. If the question were only as regards a fluid of uniform temperature, then the greatest effect would be obtained by using an inclined pipe; but the fluid, which we are now regarding, is one of a varying density and temperature, which materially alters the conditional results.

lodged from the pipes, and a ready escape provided for it. Nothing is more necessary to be attended to than this; for, in the more complicated forms of the apparatus, the want of an efficient means of discharging the air has been the cause of numerous failures. Suppose we require the apparatus fig. 3 to be filled with water; by pouring it in at the boiler, the lower pipe will of course be filled first; and the water will then gradually rise higher in the boiler until it partially fills the upper pipe. At last the orifice of the pipe *x* will become full, and the air which is in the pipe, being thus prevented from escaping, will be forced towards *c* by the weight of water behind it; and if the quantity of air be sufficiently large, it will entirely prevent the junction of the water at *c*, and cut off the communication between the two pipes. If an opening be now made in the pipe at *c*, the air will immediately escape, it being forced out by the greater density of the water; and, therefore, either a valve or a cock must be placed there, to allow of its discharge; for otherwise no circulation of the water can ensue. As water, while boiling, always evolves air, it is not sufficient merely to discharge the air from the pipes on first filling them with water, because it is continually accumulating: and in many instances, particularly with a close-topped boiler, it is desirable to have the air vent self-acting; either by using a valve, or a

small open pipe: in others a cock will be found most convenient.

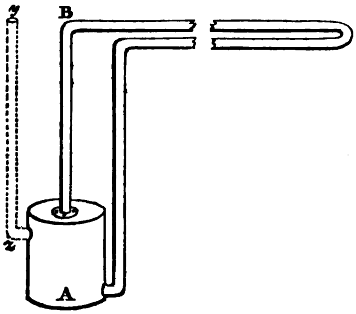
13. The size of the vent is not material, as a very small opening will be sufficient to allow the air to escape. For the rapidity of motion in fluids, being inversely proportional to their specific gravities, as water is 827 times more dense than air, an aperture which is sufficiently large to empty a pipe in 14 minutes if it contained water, would, if it contained air, empty it in about one second. Air being so very much lighter than water, it is of course necessary that the vents provided for its escape be placed in the highest part of the apparatus, for it is there it will always lodge; and sometimes it will be found necessary to have several vents in different parts of the apparatus.

Though it is perfectly easy, as far as the mere mechanical operation is concerned, to provide for the discharge of the air from the pipes, it requires much consideration and careful study to direct the application of those mechanical means to the exact spot where they will be useful. The subject will, therefore, be again adverted to in a subsequent chapter, when we have investigated the principles of the apparatus in some of its more complex forms of arrangement.

14. The plan of the boiler and pipes which has been given in the preceding figures, is applicable to comparatively but few purposes: for, in conse-

quence of the boiler being open at the top, the pipes must be laid level with it, otherwise the water would overflow. When the pipes are required to rise higher than the boiler, the latter must be closed at the top, and the pipes can then be carried upwards to any required height. This arrangement possesses considerable advantages: for the higher we make the ascending and descending pipes, the more rapid is the circulation of the water. This consequence necessarily results from the principles already explained; because, as motion is obtained in consequence of the difference in weight of the ascending and descending columns of water, the greater the height of these columns, the greater must be the difference in their weight, and therefore the greater must be the force and velocity of motion.

FIG. 5.



15. The advantages which may be derived from an increased height in the ascending pipe, cannot however be applied in an unlimited manner; because it might lead to inconvenience, and even be attended with some degree of danger to the apparatus, if the increased height were not regulated by certain rules, and these, when ascertained, applied with judgment.

16. The pressure produced by water is calculated by its columnar height, reckoned from the bottom of the vessel in which it is contained. Whether the vessel be open at the top and very deep, or closed at the top and very shallow, but with a pipe attached to the top, like the boiler and pipe A B, fig. 5, the pressure will be exactly alike in either case, if the height be similar; notwithstanding the quantity of water may be 10 times, or 100 times, larger in the one case than the other. Neither is the pressure increased, however large may be the diameter of the pipe which is used; nor is it lessened if the pipe be inserted at the side of the boiler, as in the dotted lines *y z*, fig. 5, instead of being placed on the top.

17. As the pressure of water on each square inch of surface increases at the rate of about $\frac{1}{2}$ lb.[1] for every foot of perpendicular height, if the height from the bottom of the boiler to the top of the pipe be 6 feet, the pressure on the bottom will be 3 lbs. on every square inch of surface; but if the boiler be two feet high, the pressure on the top—which will be a pressure upwards—will be only 2 lbs. on every square inch of surface, because it will only

[1] The exact weight of a perpendicular foot of water, with a base is one square inch, is 3030·24 *grains*, at the temperature of 60°; which is therefore only ·4328 of a pound avoirdupois. A column of water 30 feet high only gives a pressure of 12·68 lbs. instead of 15 lbs. as usually reckoned; and therefore the real height of a column of water which will give a pressure equal to one atmosphere must be $34\frac{1}{2}$ feet.

have 4 perpendicular feet of water above it. If the height of the pipe be increased to 28 feet, and the depth of the boiler be 2 feet, as before, making 30 feet together, the pressure will be 15 lbs. on each square inch of the bottom, 14 lbs. on each square inch of the top, and an average pressure of $14\frac{1}{2}$ lbs. on each square inch of the sides of the boiler. Suppose now, a boiler to be 3 feet long, 2 feet wide, and 2 feet deep, with a pipe 28 feet high from the top of the boiler; when the apparatus is filled with water there will be a pressure on the boiler of 66,816 lbs., or very nearly 30 tons.

18. When a great pressure is used in a hot water apparatus, in the manner here described, it is necessary that the materials of the boiler should be stronger than they otherwise need be; and more care is also required in making the joints very sound, for attaching the pipes to the boiler, so as to prevent any leakage. But when these mechanical difficulties are overcome, the amount of danger arising from a great pressure of water must not be over-rated, for it might otherwise deter some persons from adopting this form of the apparatus, notwithstanding its numerous advantages.

19. The great danger that arises from the bursting of a steam apparatus, is in consequence of the elastic force of steam, which, at very high temperatures, is immense. But water possesses very little elasticity compared with steam, its expansive

force being almost inappreciable under ordinary circumstances. At the pressure of 15 lbs. per square inch, the water in the boiler last described, which holds about 75 gallons, would be compressed rather less than *one cubic inch*, or about $\frac{1}{35}$ part of a pint[1]. The expansive force of the water in this apparatus, therefore, even supposing it were to burst, would be perfectly harmless; for it could only expand as much as it had been compressed; namely, *one cubic inch*. The effect on a boiler, by the pressure of the water, will be precisely similar to a weight pressing upon it, equal to the estimated pressure of the water; which is quite different from the sudden and violent force produced by the expansive power of steam. As an apparatus of this kind could never be forced asunder, as in the explosion of a steam boiler, the only result, under the worst circumstances that could occur, would be a leakage of the water in consequence of the cracking of some part of the boiler.

20. Neither the principle, nor the practical working of the apparatus, is in the least affected by having any additional number of pipes leading out

[1] According to the experiments of Professor Oerstead, the compression of water is ·0000461 by a pressure of 15 lbs. per square inch; and he has found that it proceeds *pari passu*, as far as 65 atmospheres, which was the limit to which his experiments extended. This compression is about equal to reducing a given bulk of water $\frac{1}{16}$ of its volume by a pressure of 20,000 lbs. per square inch.

of, or into, the boiler. The effect is the same whether there are more flow pipes than return pipes, or conversely, more return pipes than flow pipes. If there be two or more flow pipes, whether they lead from the boiler separately, or branch from one main pipe, or whether they lead from opposite sides of the boiler, or all from one side, each range of pipes will act separately and have a velocity of circulation peculiar to itself: and one range of pipes may act efficiently, while another, though attached to the same boiler, may have no circulation whatever through it; and this effect will not be altered, whether the pipes return into the boiler separately, or all unite into one main pipe. The pressure, supposing the pipes to rise vertically from the boiler, will likewise be precisely the same, however numerous the pipes may be. This circumstance is one of the peculiarities which distinguish fluids from solids. For if the fluid contained in any vessel, be pressed by the fluid in an upright pipe, so as to produce a pressure of 10 lbs. on the square inch; if a second pipe, capable of exerting a similar pressure with the first, be placed upon the same vessel, the united pressure will still be only 10 lbs. per square inch; and it would be no more, however large a number of pipes were added, provided the height were not increased.

21. One advantage may be attained by causing the water to rise from the boiler by an ascending

pipe, as in fig. 5, which cannot be accomplished by any other means; and it is of considerable importance to ascertain its true effect, as it has produced consequences which are not generally attributed to the right cause.

The force and velocity of motion of the water, being proportional to the height of the ascending and descending pipes, by increasing this height, a facility is afforded for taking the pipes below the horizontal level; as, for instance, when it is required to pass them under a doorway, or other similar obstruction, before they finally descend to the bottom of the boiler. Innumerable failures have occurred in attempting to make the water descend and again to ascend in this manner, the success of the experiment depending upon the vertical height of the ascending pipe above the boiler. These alterations of the horizontal level, which are frequently very desirable, have, of course, their limits, beyond which they cannot be carried: and it is from not having ascertained what are these limits, and what the cause of the limitation, that such uncertainty has hitherto prevailed with regard to this experiment; for it frequently succeeds, and almost, or even more more frequently fails, in practice. It will be most convenient, however, to consider this subject after we have ascertained what is the amount of the *motive power* of the water in this kind of apparatus.

CHAPTER II.

On the Motive Power of the Water—Velocity of Circulation—On increasing the Motive Power—Circulation of Water below the Boiler—Air Vents—Supply Cisterns—Expansion of Pipes, &c.

22. It has already been mentioned, that the power which produces circulation of the water, is the unequal pressure on the return pipe, in consequence of the greater specific gravity of the water in the descending pipe, above that which is in the boiler. Whether this force acts on a long length of return pipe, as *y*, *z*, fig. 2, or only on a very short length, as *f*, fig. 3, the result will be precisely similar.

23. Now, it is evident that, if this unequal pressure is the *vis viva*, or motive power, which sets in motion the whole quantity of water in the apparatus, it is only necessary, in order to ascertain the exact amount of this force, that we know the specific gravities of the two columns of water; and the difference will, of course, be the effective pressure, or motive power. This can be accurately determined

when the respective temperatures of the water in the boiler, and in the descending pipe, are known.

24. As this difference of temperature rarely exceeds a very few degrees in ordinary cases, the difference in the weight of the two columns must necessarily be very small. But, probably, the very trifling difference which exists between them, or, in other words, the extreme smallness of the motive power, is very imperfectly comprehended; and will, perhaps, be regarded with some surprise, when its amount is shown by exact computation.

25. In order to ascertain, without a long and troublesome calculation, what is the amount of motive power for any particular apparatus, the following Table has been constructed. An apparatus is assumed to be at work, having the temperature in the descending pipe 170°; and the difference of pressure upon the return pipe is calculated, supposing the water in the boiler to exceed this temperature by from 1° to 20°. This latter amount exceeds the difference that usually occurs in practice.

26. By referring to the annexed Table, it will be found that when the difference between the temperature of the ascending and the descending columns, amounts to 8°, the difference in weight is 8·16 *grains* on each square inch of the section of the return pipe, supposing the height of the boiler (A, fig. 2) to be 12 inches. This height, however,

is only taken as a convenient standard from which to calculate; for, probably, the actual height will seldom be less than about 18 inches, and, in many cases, it will be considerably more.

Now, suppose, in such a form of apparatus as fig. 2, the boiler to be 2 feet high; the distance from the top of the upper pipe to the centre of the lower pipe to be 18 inches; and the pipe 4 inches diameter;—if the difference of temperature between the water in the boiler, and in the descending pipe, be 8°, the difference of pressure on the return pipe will be 153 *grains*, or about the third part of an ounce weight: and this will be the amount of *motive power* of the apparatus, whatever be the length of pipe attached to it. If such an apparatus have 100 yards of pipe, 4 inches diameter, and the boiler contains, suppose 30 gallons;—there will be 190 gallons, or 1900 lbs weight of water, kept in continual motion by a force only equal to one-third of an ounce. This calculation of the amount of the motive power, in comparison with the weight moved, will vary under different circumstances; and in all cases the velocity of the circulation will vary simultaneously with it.

Difference in Weight of Two Columns of Water, each One Foot high, at various Temperatures.

Difference in Temperature of the Two Columns of Water: in Degrees of Fahrenheit's Scale.	Difference in Weight of Two Columns of Water contained in different sized Pipes.				Difference of a Column 1 foot high.
	1 in. diam.	2 in. diam.	3 in. diam.	4 in. diam.	per sqr. in.
	grs. weight	grs. weight	grs. weight	grs. weight	grs. weight
2°	1·5	6·3	14.3	25 4	2·028
4°	3·1	12·7	28 8	51·1	4·068
6°	4·7	19·1	43·3	76·7	6·108
8°	6·4	25·6	57·9	102·5	8·160
10°	8·0	32·0	72·3	128·1	10·200
12°	9·6	38·5	87·0	154·1	12·264
14°	11·2	45·0	101·7	180·0	14·328
16°	12·8	51·4	116·3	205·9	16·392
18°	14·4	57·9	131·0	231·9	18·456
20°	16·1	64·5	145·7	258·0	20·532

*** The above Table has been calculated by the formula given with Table 4, for ascertaining the specific gravity of Water at different temperatures. The assumed temperature is from 170° to 190°.

27. It will be observed in the foregoing table, that the amount of motive power increases with the size of the pipe: for instance, the power is 4 times as great in a pipe of 4 inches diameter, as in one of 2 inches. The power, however, bears exactly the same relative proportion to the resistance, or weight of water to be put in motion, in all the sizes alike; for although the motive power is four times as great in pipes of 4 inches diameter, as in those of 2 inches, the former contains four times as much water as the

latter: the power and the resistance, therefore, are relatively the same.

28. As the motive power is so small, it is not at all surprising that, by an injudicious arrangement of the different parts of an apparatus, the resulting motion may frequently be impeded, and sometimes even totally destroyed: for the slower the circulation of the water, the more likely is it to be interrupted in its course. There are two ways by which the amount of the motive power may be increased: one, by allowing the water to cool a greater number of degrees between the time of its leaving the boiler, and the period of its return through the descending pipe; the other, by increasing the vertical height of the ascending and descending columns of water. The effects produced by these two methods are precisely similar; for by doubling the difference of temperature between the flow pipe and the return pipe, the same increase in power is obtained as by doubling the vertical height; and tripling the difference in temperature is the same as tripling the vertical height [1]. This can be ascertained by referring to the preceding Table. Thus, suppose, when the difference of temperature is 8°, and the vertical height 4 feet, that the motive power is 32·6 *grains* per square inch: if the difference of temperature be increased to 16° while the height remains the same,

[1] This is without reference to friction: the effect will therefore be a little modified by this cause. (See art. 34 & 55.)

or if the height be increased to 8 feet while the temperature remains as at first;—the pressure, in either case, will be 65·2 *grains* per square inch, or twice the former amount. The same rule applies to other differences, both of height and temperature.

29. Almost the only two methods of increasing the difference of temperature between the ascending and the descending columns, are, either by increasing the quantity of pipe, so as to allow the water to flow a greater distance before it returns to the boiler; or, by diminishing the diameter of the pipe, so as to expose more surface in proportion to the quantity of water contained in it, and by this means to make it part with more heat in a given time. (See art. 72.) The first of these two methods, however, is necessarily limited by the extent of the building that is to be heated, to which the quantity of pipe must be adjusted in order to obtain the required temperature: and as to the second, there are many objections against reducing the size of the pipes, which will be considered presently. The increase of motive power to be obtained by increasing the height of the ascending column of water, is, therefore, what must principally be depended on, when additional power is required to overcome any unusual obstructions.

30. In all cases the rapidity of circulation is proportional to the motive power; and, in fact, it is the index and the measure of its amount. For if, while

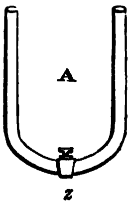
the resistance remains uniform, the motive power be increased in any manner or in any degree, the rate of circulation will increase in a relative proportion. Now the motive power may be augmented, as we have already seen, either by increasing the vertical height of the pipe; by reducing its diameter; or by increasing its length. If by any of these means the circulation be doubled in velocity, then, as the water will pass through the same length of pipe in half the time it did before, it will only lose half as much heat as in the former case; because the rate of cooling is not proportional to the distance through which the water circulates, but to the time of transit. If, then, by sufficiently increasing the vertical height, the difference between the temperature of the flow pipe and the return pipe be diminished one-half, it might be supposed that the motive power of the apparatus would remain the same, and no advantage would appear to be gained by this means. But this is not exactly the case. For although, whether we double the vertical height, or double the horizontal length, we shall, in either case, increase the velocity of motion; yet, it will require a quadruple increase of vertical height, or a quadruple increase of horizontal length, to obtain double the original rate of circulation. (See art. 33.) The increased velocity is therefore indicative of increased power: and, in a hot water apparatus, it is the increased velocity of

circulation, which overcomes any obstructions of a greater amount than ordinary.

31. The velocity with which the water circulates in this kind of apparatus, although continually subject to variation, can nevertheless be calculated theoretically, when certain data are agreed upon, or are ascertained to exist.

32. When the two legs of an inverted syphon, A fig. 6, are filled with liquids of unequal density, if the stop cock, *z*, be turned, so as to open the communication between them, the lighter liquid will move upwards with a force proportional to the difference of weight of the two columns, provided the bulk of the two liquids be equal. If one leg contains oil, and the other contains water, the relative weights will be about as 9 to 10; therefore it will require 10 inches vertical height of oil, to balance 9 inches of water; and no motion will in that case take place. But when equal bulks of the two fluids are used, the velocity of motion with which the lighter fluid is forced upwards, is equal to the velocity which a solid body would acquire in falling, by its own gravity, through a space equal to the additional height which the lighter body would occupy in the syphon, supposing a similar *weight* of each fluid had been used. This velocity is easily calculated:—a gravitating body falls 16 feet in the first second of time of its descent; 64 feet in

FIG. 6.



two seconds, and so on; the velocity increasing as the square of the time: therefore, the relative velocities are, as the *square roots of the heights.* Now, in the case of the syphon, which we have supposed to contain a column of water and a column of oil, each 9 inches in height; as the oil ought to be 10 inches high to balance the 9 inches of water, the oil in the one leg will be forced upwards with a velocity equal to that which the water (or any other body) would acquire by falling through one inch of space; and this velocity, we shall find, is equal to 138 feet *per minute*[1].

33. To estimate the velocity of the motion of the water, in a hot-water apparatus, the same rule will apply. If the average temperature be 170°, the difference between the temperature of the

[1] The velocity will be as the square root of 16 feet *per second*, to the square root of the additional height which an equal weight of the lighter liquid would occupy, reduced to the decimal of a foot. And as the acquired velocity of a body is twice as much as the distance it passes through, in arriving at any given velocity by accelerated motion; or, in other words, as a body which falls through 16 feet of space, in one second, will proceed at the rate of 32 feet per second afterwards, without receiving any additional impulse; so the velocity found by this rule will be only half the real velocity; and the number thus obtained must be multiplied by 2. The velocity will, therefore, be found, by multiplying the *square root* of the difference between the height of the two columns, by the *square root* of 16; and then, multiplying that product by 2, will give the real velocity *per second*.

The discharge through a syphon, employed to empty casks and other vessels, can also be calculated by this rule: the velocity of motion will be equal to the difference in length of the two legs.

ascending and the descending columns 8°, and the height 10 feet; when similar weights of water are placed in each column, the hottest will stand ·331 of an inch higher than the other[1]; and this will give a velocity equal to 79·2 feet *per minute.* If the height be 5 feet, the difference of temperature remaining as before, the velocity will be only 55·2 feet *per minute:* but if the difference of temperature in this last example had been double the amount stated,—that is, had the difference of temperature been 16°, and the vertical height of the pipe 5 feet,—then the velocity of motion would have been 79·2 feet *per minute,* the same as in the first example, where the vertical height was 10 feet, and the difference of temperature 8°. This, therefore, proves, in corroboration of what has been already stated (art. 30), that reducing the temperature of the water, either by using smaller pipes, or by increasing the length through which it flows, has the same effect on the circulation as increasing the vertical height. The velocity for 3 feet of vertical height by the same rule will be 43·2 feet *per minute;* for 2 feet of vertical height, it will be 36 feet *per minute;* and for 18 inches of vertical height it will be 30·7 feet *per minute,* if the difference of temperature between the two columns be in each case 8°, the same as in the former examples. It must here be observed, how-

[1] The expansion of water by heat, will be found by Table IV.

ever, that although it appears by these calculations, that increasing the vertical height of the pipe fourfold, will produce a double velocity of circulation, as the water will then pass through the pipe in half the time, the difference between the temperature of the flow pipe and the return pipe will be lessened one half, and the velocity will at last become a mean rate: so that the mere quadruple increase of vertical height, without the horizontal length be at the same time increased, will only produce a rate of circulation about one and a half times the original velocity.

34. Such is the result of theory: but, although this is true in itself, we shall, in practice, find but few cases that in any way agree with these results, in consequence of other causes modifying the effects. In an apparatus in which the length of pipe is not very considerable, where the pipes are of large diameter, and the angles few, a deduction, according to the circumstances, of from 10 to 20 per cent. from the theoretical amount, will represent, with tolerable accuracy, the true velocity. But in more complex apparatus, no approximation can be obtained by this means; for the velocity of circulation in such cases becomes so much reduced by friction, that it will sometimes require from 50 to 90 per cent. and upwards, to be deducted from the calculated velocity, in order to obtain the true rate of circulation. The calculation of the friction of water passing

through pipes, is alike complicated and unsatisfactory: though the question has been investigated by some of the most able philosophers and mathematicians, a simple and correct formula on this subject is still a desideratum; and in the present state of knowledge of the subject, it would be almost impossible to determine what would be the resulting velocity of circulation, in a hot water apparatus of complicated construction[1].

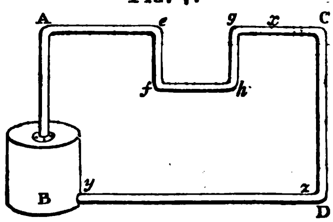
35. In addition to these causes which impede the circulation, there is another that is still more important. The vertical angles in the pipe, or those angles which carry the pipe below the horizontal level, increase the resistance to a very considerable extent; for they oppose not merely a passive resist-

[1] M. Prony and M. Bossut calculate the velocity to be *inversely* as the square root of the length of pipe, and also, *directly* as the square of the velocity. The formula of Prony for the friction of straight pipes is $v = 26{\cdot}79 \sqrt{\frac{DZ}{L}}$ where v represents the mean velocity; D the diameter of the pipe; Z the altitude of the head of water; L the length of the pipe in metres. The various formulæ of Bossut, Girard, Eytelwein, and others, are too complicated to be introduced here: (see Prony, On the Motion of Fluids, *Mémoires des Savans Etrangers*, &c., 1835:—Eytelwein's Hydraulics by Nicholson:—Brit. Sci. Reports, vol. II., &c.) Mr. G. Rennie (Phil. Trans. 1831), has given the result of some experiments on this subject. He found that the velocity in a $\frac{1}{2}$ inch pipe, was reduced nearly three-fourths (that is, from 3·7 to 1), by increasing its length from 1 foot to 30 feet; that 3 semicircular bends reduced the velocity $\frac{1}{36}$ in a short pipe, and 14 such bends reduced it $\frac{1}{20}$ of its velocity: while 24 right angled bends reduced the velocity nearly two-thirds. The pipe in each case was only $\frac{1}{2}$ inch diameter.

ance by friction, but they engender a force of their own, tending in an opposite direction to that of the prime moving power.

36. The motion of the heated particles of water is very different in passing through an ascending pipe, compared with that which takes place in a descending pipe. The heated particles rise upwards through an ascending pipe with great rapidity, and when the space occupied by the displaced particles is supplied by water from below, the motion becomes general, in one direction, being most rapid in the centre, and gradually decreasing towards the circumference, where, on account of the friction, it becomes comparatively slow. But in a descending pipe, the circumstances are very different, the motion being much more like that of a solid body. For as the heated particles are unable to force their way downwards through those which are colder and heavier than themselves, the only motion arises from the cold water flowing out at the bottom, its place being then supplied at the top by that which is warmer; the whole apparently moving together, instead of the molecular action, which has been described as the proper motion in an ascending pipe.

Fig. 7.



37. In an apparatus constructed as fig. 7, the motion through the boiler and pipe A, B, and through the descending pipe C, D

takes place according to the two methods here described. But it is evident that, on motion commencing in the return pipe *y*, *z*, in consequence of the greater pressure of C, D, than of A, B, the water from A will be forced towards *e*, at the same time that the water in *e*, *f*, *g*, *h*, flows towards C. But when a very small quantity of hot water has passed from the pipe and boiler A, B, into the pipe *e*, *f*, the column of water *g*, *h*, will be heavier than the column *e*, *f*, and therefore there will be a tendency for motion to take place along the upper pipe, *towards* the boiler instead of from it. This force, whatever be its amount, must be in opposition to that which occurs in the lower or return pipe, in consequence of the pressure of C, D, being greater than A, B; and, unless, therefore, the force of motion in the descending pipe C, D, be sufficient to overcome this tendency to a retrograde motion, and leave a residual force sufficient to produce direct motion, no circulation of the water can take place.

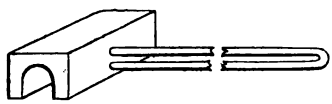
38. An extremely feeble power will produce circulation of the water, in an apparatus where there are no unusual obstructions; but it is a necessary result of the motive power being so very small, that it is easily neutralized. I have known so trifling a circumstance as a thin shaving planed off a piece of wood, by accidentally getting into a pipe, effectually prevent circulation in an apparatus otherwise perfect in all its parts.

39. It is not sufficient, then, when such an obstruction as the vertical declination from the horizontal level, shown by the last figure, has to be surmounted, merely to make the *direct* force of motion sufficient to overcome the antagonist force, and to leave the smallest possible residual amount for the purpose of causing circulation; because an amount which would be sufficient for this purpose, as an undivided force, would not be found sufficient as a residual force.

40. In estimating the additional height, which it is necessary to give to the ascending column, in order to overcome such an obstruction as shown in fig. 7, it will be necessary to take into account what is the length and diameter of the pipe through which the water passes, between the time of its egress and regress; for on this depends the difference of temperature between the ascending and descending columns, which, we have seen, materially affects the amount of the motive power of the apparatus. If the length of pipe be considerable, a smaller increase of the vertical height of the ascending pipe will suffice; but if the length of pipe be short, a greater height must be allowed. The temperature to which the air surrounding the pipes is to be raised, will also modify the result; for on this will depend the quantity of heat given out by the pipes *per minute*, which likewise affects the temperature of the descending pipe. (Art. 96.)

41. Under such a great diversity of circumstances, it would be difficult to form a rule for estimating what ought to be the height of the ascending pipe in such cases; because, not only are these circumstances different in each apparatus, but they likewise differ, in some respects, in the same apparatus, in the different stages of its working. The difficulty is also increased by not being able to fix on an absolute minimum measurement, which is sufficient, under all circumstances, to cause a circulation of the water in the common form of the apparatus. There have been instances where apparatus have succeeded, though constructed on the very worst principles, in consequence of various circumstances having favoured the result. Thus in an apparatus, constructed as fig. 8, where the pipes were not more than 3 inches

Fig. 8.



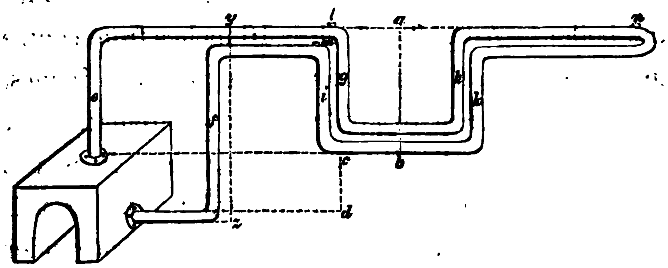
apart, the water circulated with perfect freedom; but in this case, not only was the pipe of considerable length, and without angles, or turns, but the size of the pipe was only two inches diameter, so that the water cooled twice as fast as it would have done had pipes of four inches diameter been used (Art. 72). It is, however, quite certain that such a distance between the pipes, at their insertion into the boiler, as that which has just been described, is insufficient, under ordinary circumstances, to give a steady and good circulation. But when the two pipes are about

12 inches apart, at the place of their insertion into the boiler ($x\ f$, fig. 3), which is 16 inches from centre to centre when the diameter of the pipe is 4 inches, it will be sufficient to produce a good circulation for almost any ordinary length of pipe, when it is not required to dip below the horizontal level. If this be considered as the minimum height which, under ordinary circumstances, will obtain a good circulation when the pipes are not required to dip below the horizontal level, then an average height can be estimated for enabling any vertical declination of the pipes to be made.

42. In such cases the height of the ascending pipe should generally be just so much greater than the above dimensions, as the depth which the circulating pipe is required to dip below the horizontal level; bearing in mind the circumstances mentioned, art. 40, which modify the general results[1]. Thus suppose the depth of the dip, shown by the dotted line a, b, fig. 9, to be 24 inches; then the distance y, z, ought to be 40 inches, if the pipes be 4 inches diameter; that is 36 inches from centre to centre,

[1] So greatly, in fact, do these circumstances affect the general result, that it is very possible, if the pipes be of small diameter, and of great length, to make them descend below the bottom of the boiler to a considerable depth. It is therefore evident that the dimensions which are here given for the height of the ascending pipe relatively to the dip, must not be taken as an absolute minimum, but simply as a general rule which will succeed in all cases. See Art. 44 and 45.

Fig. 9.



or 40 inches from the top of the pipe *y* to the bottom of the pipe *z*: and with these dimensions, as good a circulation will be obtained, as when the distance between the top and bottom pipes is 16 inches from centre to centre, in the common form of the apparatus. It will be observed that, by this arrangement, the distance *c*, *d*, from the under side of the flow pipe to the upper side of the return pipe, is just 12 inches, which is the same height that was stated to be necessary to insure a good circulation, on the ordinary plan, without a vertical dip. The reason why this height is sufficient in the present case, notwithstanding the increased friction of the angles, is because there must always be a greater difference between the temperature of *e* and *f*, than between either *g* and *h*, or between *i* and *k*, or even more than between both these together; therefore the tendency to *direct* motion is greater than towards retrograde motion, in proportion to this difference, and is sufficient to overcome the increased friction caused by the vertical declination: while the additional height of 12 inches

beyond the height of the dip, possessed by the descending pipe *f*, is sufficient to produce circulation of the water. If *g* and *h*, and also *i* and *k*, were very wide apart, say 40 or 50 feet, instead of being, as usual, only about 3 or 4 feet, the balance of effect, though still in favour of *direct* motion, would not be so great as in the last supposed case; because there would be a greater difference in temperature between *g* and *h*, (that is, *h* would be heavier than *g* in a greater degree), which would give a greater tendency to retrograde motion. In extreme cases, therefore, it will be advisable to make the ascending pipe somewhat higher in proportion to the dip than is here stated, particularly when there are several such alterations required in the level of the pipes; and, in all cases, as has been before observed, the higher the ascending pipe is made, the more rapid will be the circulation.

43. The difficulty of producing circulation of the water in this form of the apparatus, is always greater on every occasion of first lighting the fire; because the temperature of the two pipes, which form the ascent and descent of the dip, will always be more nearly equal when the whole of the apparatus has become hot. If, therefore, a small suction-pump be attached to the upper pipe at *x*, fig. 7, and, after the water in the boiler has become heated, a few strokes of the pump be made, so as to draw the hot water from the boiler through the *upper* pipe, circulation

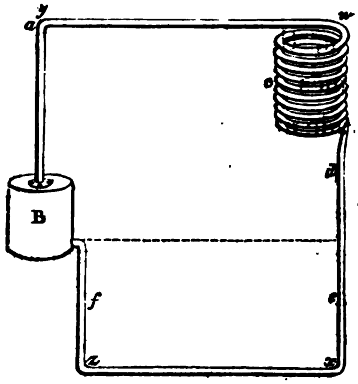
may be produced in an apparatus which, without this assistance, would never act at all. For it is evident that when the ascending and descending pipes of the dip are nearly close to one another, if circulation be once obtained, the water will lose so very little of its heat during its transit through this short distance, that the tendency to retrograde motion will be but very small. A pump is, however, by no means a desirable addition to the apparatus, when it can possibly be avoided; for not only will it be more liable to derangement, but greater attention will be necessary in setting it to work: for the water must first be warmed in the boiler, and then the circulation must be produced by using the pump. It will, therefore, only be desirable to adopt it, when a sufficient height for the ascending pipe of the boiler cannot be obtained, to produce circulation without this assistance.

What has here been observed with respect to the height of the ascending pipe, relatively to the vertical declination, or dip, below the level of the horizontal pipe, applies to all the usual forms which are given to the apparatus. But there are peculiar arrangements which may be adopted, that will allow the dip of the circulating pipe to be much greater in proportion to the vertical height above the boiler, than has here been stated; for, in some cases, the dip-pipes may even pass below the bottom of the boiler to a considerable depth, without destroying

the circulation. This plan is not very dissimilar to that adopted by the Marquis de Chabannes, about twenty years ago.

44. In such an arrangement of pipes as fig. 10, the circulation depends entirely upon the quantity of heat given off by the coil *c*; for it is evident that, when the boiler B and pipe *a* are heated, the *direct* motion will arise in consequence of the greater weight of the water in the coil *c* and pipe *d*, above that which is in the boiler and pipe B, *a*. But as the water in the pipe *e*, below the dotted line, will be lighter than that in the pipe *f*, the tendency in that part of the apparatus will be towards a retrograde motion. The result of these two forces will be, that if the water in the whole length of pipe *w*, *x*, is heavier than that of the whole length *y*, *z*, in a sufficient degree to overcome the friction, circulation of the water will take place; and the velocity of motion will depend upon the amount of this difference in weight.

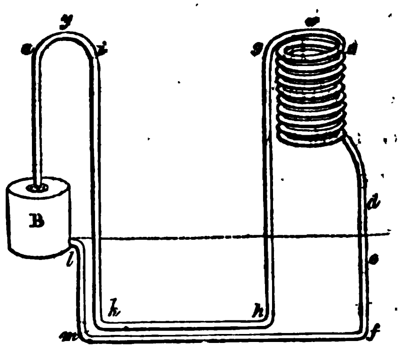
FIG. 10.



45. Another form, though somewhat more complicated, may be given to this arrangement of the apparatus. In fig. 11, B represents the boiler; and

the effective or *direct* motion is, in this case, caused by the water in the coil and pipe *c*, *d*, being so much heavier than that in the boiler and pipe B, *a*, that it overcomes the retrograde motion which is produced by all the other parts of the apparatus. Thus the water in *g*, *h*, being *heavier* than that in *i*, *k*; and that in *e*, *f*, (below the dotted line) being *lighter* than that in *l*, *m*, has, in both cases, a tendency to retrogression; and this will be more considerable in proportion as the pipes *i*, *k*, and *g*, *h*, &c., are more distant from each other. The motive power, therefore, entirely depends upon the quantity of heat given off by the coil; for the water must be cooled down many degrees, in order to give it a sufficient preponderance over the water in B, *a*, to cause a circulation.

Fig. 11.



46. If the coil, in the two last figures, be placed in any position lower down than it is here shown, the effect will be proportionally less; and if placed below the dotted lines, it would be scarcely possible to obtain any circulation at all. Nor would there be any circulation if the coil were omitted, because the mere descent of the water through a straight

pipe, would not cool it sufficiently to give the necessary preponderance to the descending pipe, unless some other contrivance, for the purpose of cooling the water an equal extent, were adopted.

47. Many other arrangements of the apparatus answering the same purpose as these last two figures, might be contrived; but it may be observed, that these descriptions have been introduced principally to show that the notion that it is impossible to make water descend and circulate below the boiler, is erroneous. It, however, requires great judgment in adopting any such form of the apparatus as this, for many concurring circumstances are essential for its complete success.

48. In a complicated arrangement of the apparatus, it is sometimes so very difficult to detect the various causes of interference, and the impediments which arise are often apparently so insignificant in their extent, that even when ascertained, they are frequently neglected. Those, however, who bear in mind how small is the amount of motive power in any apparatus of this description, will not consider as unimportant, any impediment, however small, which they may detect; but in the more complicated forms of the apparatus, so many causes become operative, that the reason of failure may sometimes elude the detection of even an experienced practitioner.

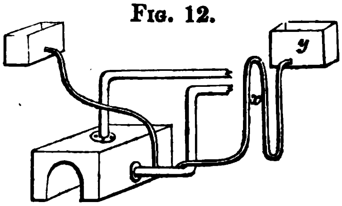
49. The necessity of making provision for the escape of the air from the pipes, has already been

mentioned. It may be observed, that in such forms of the apparatus as described in the last three figures, the difficulty of its expulsion is much increased, as there are several points where it will collect and stop the circulation, unless proper means be taken to prevent this result. In the apparatus fig. 9, the air will collect at three points *l*, *m*, and *n*; and the nature of the outlets provided for its escape, will depend, in some measure, upon the plan adopted for supplying the apparatus with water. It frequently requires the greatest care and the closest attention, to discover where the air is likely to lodge, as the most trifling alteration in the position of the pipes will entirely alter the arrangements with respect to the air vents. Want of attention to this has been the cause of many failures; and the discovery of the places where the air will accumulate, is, occasionally, a matter of some difficulty. For although it be true, in a general sense, that the air will rise to the highest part of the apparatus, it will frequently be prevented getting to those parts by alterations in the level of the pipes, and by other causes. This is the case at *m*, fig. 9, where, it will be seen, the air which accumulates in that part of the apparatus is prevented from escaping to a higher level, by the vertical angle at *f*, on the one side, and *i*, on the other. In the apparatus, fig. 11, the air will accumulate at *y*, and at *w*, and must be carried off by proper outlets.

50. When a boiler has an open top, or merely a loose cover laid on it, no particular care is necessary respecting the supply of water. It can generally be poured in at the boiler, taking care not to fill it quite full, so as to allow for the expansion of the water when heated, as otherwise it will overflow. But when (as in figures 7, 9, 10, and 11,) the boiler is close at the top, it is usual to place a supply cistern on a level with, or above the highest part of the apparatus, so as to keep it always full of water. But as water expands about $\frac{1}{24}$ part of its bulk, when it is heated from 40° (the point of its greatest condensation,) to 212°; it is indispensably necessary to provide for a part of the water returning back to the supply cistern, when this expansion takes place. The cistern, however, needs not contain so much water as $\frac{1}{24}$ part of the whole contents of the apparatus; for it is found, in practice, that a much less quantity than this returns back into the cistern on the apparatus being heated. This arises from the fact of the water not reaching to so high a temperature as 212°, and also in consequence of its being generally at a higher temperature than 40°, before it is heated, and by both these causes, the expansion is considerably lessened; for if the water be raised from 50° to 180°, the expansion will only be about $\frac{1}{36}$ part of its bulk, and the expansion of the iron itself, by giving an increased capacity to the apparatus, will also tend still farther to diminish the quantity of water returned back into the cistern.

51. The usual plan for a supply cistern is shown in fig. 12. The cistern is placed in some convenient situation, and then attached, by a small pipe, to any part of the apparatus,—usually, to the lower pipe, as it is then less likely to allow of the escape of vapour, than if it were fastened to the top of the boiler.

Fig. 12.



But a still better plan is to bend the pipe, attached to the cistern, into the form shown by *x*, *y*, which is a preventive to the escape of any heat or vapour at that part, as the legs of the inverted syphon *x* generally remain quite cold.

52. One very important part of the subject of expansion, is the necessity which exists for allowing sufficient room for the elongation of the pipes when they become hot. Want of attention to this has caused several accidents; for the expansive power of iron, when heated, is so great, that scarcely anything can withstand it. The linear expansion of cast iron, by raising its temperature from 32° to 212°, is ·0011111, or about $\frac{1}{900}$ part of its length, which is nearly equal to $1\frac{3}{8}$ inches in 100 feet. Therefore it is necessary to leave the pipes unconfined, so that they shall have free motion lengthways, to this extent at least; and instead of confining them, as sometimes has been done, facilities should be provided for their free expansion, by laying small rollers

under them at various points: for as the contraction on cooling is always equal to the expansion on heating, unless they can readily return to their original position when they become cool, the joints are very likely to get loose, and to become leaky.

CHAPTER III.

On the Resistance by Friction—Relative Sizes of Main Pipes and Branch Pipes—Size of Connecting Pipes, Cocks, &c.

53. WHEN treating, in the preceding chapter, on the velocity of the circulation of the water, it was observed that the theoretical velocity is always reduced by friction. Although the calculations of the friction of water, in passing through pipes, is intricate [1], the *relative* friction for different sizes of pipes is easily ascertained; and this appears to be all that is necessary to be acquainted with, for the purpose of the present inquiry.

54. The friction occasioned by water passing through small pipes, is very much greater than in those which are larger. This arises from two causes: the increased surface with which a given quantity of water comes into contact, by passing through a small pipe; and the greater velocity with which the water

[1] See Art. 34.

circulates, in consequence of losing more heat per minute[1].

55. The relative friction for different sizes of pipe, when the velocity with which the water passes is the same in all, may be seen in the following Table:

Diameter of Pipes	½.	1.	2.	3.	4.	inches.
Friction	8.	4.	2.	1·3.	1.	

Taking the friction, in pipes of 4 inches diameter, as unity,—that of a pipe 2 inches diameter is twice as much, and a 1-inch pipe four times as much as the pipe of 4 inches; the friction being as the surface *directly*, and the whole quantity of water *inversely*.[2]

56. The friction which arises from increased velocity, is nearly *as the square of the velocity;* but this calculation is unnecessary to enter into here, because the velocity of circulation of the water, in a hot-water apparatus, is constantly subject to fluctuation: for as the friction increases with the velocity of circulation, so the velocity is checked by the increased friction; and it finally assumes a mean rate, proportioned to the friction on the one hand, and the theoretical velocity on the other, calculated ac-

[1] See Chap. IV. art. 72. This latter remark of course only applies to water circulating in a hot-water apparatus: the former applies to all cases of hydraulics.

[2] Nicholson's Journal, Vol. iii., page 31.

cording to the rule (art. 33,) in the preceding chapter.

57. Closely connected with the subject of friction, is the question of the proper size for leading, or main pipes. It has been supposed by many, that where two or more circulating pipes are attached to one main pipe, the area, or section, of the main pipe, ought to be equal to the sum of the areas of all the branch pipes. This has led to the most inconvenient arrangements having been resorted to in particular cases. In some instances, pipes of 9 inches diameter have been used for the main pipes, where those of 4 inches would have answered the purpose infinitely better.

58. It has been already explained (art. 36) why the motion of water is more rapid in an upright, than in a horizontal pipe. If four branch pipes are supplied by one upright main pipe, this latter needs be very little, if any, larger than the circulating pipe: but if only two, or even three, branches are to be supplied by one main pipe, it will be quite unnecessary that the main pipe should be any larger than the branches, unless the length of the horizontal pipe be unusually great. If the branches exceed this number, it may be desirable to increase the diameter of the main pipe, in a moderate degree: but the motion of the water through it, however, will be just so much the more rapid, in proportion as there are more branches for it to discharge the water

into: for it is evident, that if the outlet from the boiler be by a pipe 4 inches diameter, the flow of water will be more impeded, than if a pipe of 6 inches diameter were used; and the water will be specifically lighter in the boiler than in the descending pipe, in a greater degree in the former case, than in the latter; and this will consequently cause a more rapid circulation through the apparatus: but though the friction of the water will be greater in the ascending pipe by this arrangement, yet it will not be of much importance, except when very small pipes are used.

59. Another advantage will arise from this arrangement, in consequence of a small pipe, *under these circumstances*, losing less of its heat than a large one. For, suppose four branch pipes, 4 inches diameter, are to be supplied by one main pipe; one pipe of 8 inches diameter would have the same sectional area as the four pipes of 4 inches diameter: but if instead of being 8 inches diameter, the main pipe be made only 4 inches diameter, then the water must travel four times as fast through this pipe, as it would do through the one of 8 inches diameter, in order to supply the same quantity of heat to the branch pipes. This it will do very nearly; and it may easily be deduced, that, under these circumstances, the water will only lose one half as much heat by passing through the small pipe, as it would in passing through the larger one.

60. On the same principle, it will frequently be found exceedingly convenient, when two rooms or buildings, somewhat distant from each other, are required to be warmed by one boiler, to make the connecting pipe between them much smaller than the pipe used for radiating the heat to warm the buildings. For, on the principle already mentioned, there will be a saving, as well in heat, as in the cost of the apparatus, by reducing the size of the pipe in that part which is not required to give off heat, but which is merely used to connect different parts together[1].

61. The same rule may likewise be followed, where stop-cocks are required occasionally to shut off the communication between different parts of an apparatus, so as only to warm one particular room or part of a building. The cocks used for this purpose, need not be near so large as the bore of the pipes; for exactly in proportion as they are smaller, so

[1] As all alterations in the size of the pipe, either by enlarging or contracting its diameter, materially alters the velocity of circulation of the water, care should be taken that these alterations be not made without some decided advantage appears to be attainable by so doing. Venturi found by experiment, that enlargements in a pipe reduced the velocity of discharge as follows:—When a given quantity of water was discharged through

A straight pipe in	109″
A pipe with 1 enlargement, required	147″
——— 3	192″
——— 5	240″

much the more rapidly will the water pass through the obstruction [1]. Some judgment, however, must be exercised in all such cases: for both with connecting pipes and cocks, if the size be very disproportionate, the free circulation of the water will of course be impeded. In most cases, a cock of 2 inches diameter, will be sufficiently large to use with pipes of 4 inches diameter; and a cock of 1½ inch diameter, with pipes of 3 inches diameter: but for very small pipes, the relative proportions should perhaps be more nearly equal, on account of the increased friction.

62. Though some of these propositions may appear to be at variance with the laws of hydraulics, they will nevertheless be found correct; because several of the effects are to be referred either entirely to hydrostatic laws, or to a complicated result of hydrodynamics; and therefore they are not to be judged of by simple hydraulic principles. In fact, the correctness of the theories advanced in this treatise, which are of a practical character, and admit of verification, have been tested, more or less extensively, by actual experiment, and do not, therefore, rest merely on hypothetical reasoning.

[1] As this may at first appear doubtful, it should be borne in mind, that this kind of obstruction to the circulation, will cause a greater difference between the temperature of the flow pipe and the return pipe; and, when this occurs, the velocity of the circulation must always be increased.

CHAPTER IV.

Permanence of Temperature—Rates of Cooling, for different sized Bodies—Relative Size of Pipes and Boilers—Objections against Small Boilers—Proper Size of Boilers, for any given Length of Pipe.

63. One of the greatest advantages which the plan of heating by the circulation of hot water possesses over all other inventions for distributing artificial heat, is, that a greater permanence of temperature can be obtained by it, than by any other method. The difference between an apparatus heated by hot water, and one where steam is made the medium of communicating heat, is no less remarkable in this particular, than in its superior economy of fuel.

64. It seldom happens that the pipes of a hot-water apparatus can be raised to so high a temperature as 212°; and in fact, it is not desirable to do so; because steam would then be formed, and would escape from the air vent, or safety pipe, without affording any useful heat. Steam pipes, on the

contrary, must always be at 212° at the least, because, at a lower temperature, the steam will condense. A given length of steam pipe, will therefore afford more heat than the same quantity of hot-water pipe: but, if we consider the relative permanence of temperature of the two methods, we shall find a very remarkable difference in favour of pipes heated with hot water.

65. The weight of steam at the temperature of 212°, compared with the weight of water at 212°, is about, as 1 to 1694; so that a pipe which is filled with water at 212°, contains 1694 times as much *matter* as one of equal size filled with steam. If the source of heat be withdrawn from the steam pipes, the temperature will soon fall below 212°, and the steam immediately in contact with the pipes will condense: but in condensing, the steam parts with its *latent heat;* and this heat in passing from the latent to the sensible state, will again raise the temperature of the pipes. But as soon as they are a second time cooled down below 212°, a further portion of steam will condense, and a further quantity of latent heat will pass into the state of heat of temperature[1]; and so on until the whole quantity of latent heat has been abstracted, and the

[1] The heat of temperature is that which is appreciable by the thermometer; and the term is used in contra-distinction to *latent* heat, which is not capable of being measured in a direct manner by any instrument whatever.

whole of the steam condensed, in which state it will possess just as much heating power, as a similar bulk of water at the like temperature; that is, the same as a quantity of water occupying $\frac{1}{1694}$ part the space which the steam originally did.

66. The specific heat of uncondensed steam compared with water, is, for equal weights, as ·8470 to 1: but the latent heat[1] of steam being estimated at 1000°, we shall find the relative heat obtainable from *equal weights* of condensed steam, and of water, reducing both from the temperature of 212° to 60°, to be as 7·425 to 1; but for *equal bulks*, it will be as 1 to 228; that is, bulk for bulk, water will give out 228 times as much heat as steam, on reducing both from the temperature of 212° to 60°. A given bulk of steam will therefore lose as much of its heat in one minute, as the same bulk of water will lose in three hours and three quarters.

67. When the water and the steam are both contained in iron pipes, the rate of cooling will, however, be very different from this ratio; in consequence of the much larger quantity of heat which is contained in the metal itself, than in the steam with which the pipe is filled.

[1] The results of different experiments on the subject of the latent heat of steam, although somewhat various, are yet sufficiently near for all practical purposes. Watt's experiments give 900° to 950°; Lavoisier and Laplace, 1000°; Mr. Southern 945°; Dr. Ure, 967° to 1000°; and Count Rumford, 1000°.

68. The specific heat of cast-iron being nearly the same as water (see Table V.); if we take two similar pipes, 4 inches diameter, and $\frac{1}{4}$ of an inch thick, one filled with water, and the other with steam, each at the temperature of 212°; the one which is filled with water will contain 4·68 times as much heat as that which is filled with steam: therefore if the steam pipe cools down to the temperature of 60° in one hour, the pipe containing water would require four hours and a half, under the same circumstances, before it reached the like temperature. But this is merely reckoning the effect of the pipe and of the fluid contained in it. In a steam apparatus this is all that is effective in giving out heat: but in a hot-water apparatus, there is likewise the heat from the water contained in the boiler, and even the heat from the brick work around the boiler; which all tends to increase the effect of the pipes, in consequence of the circulation of the water continuing long after the fire is extinguished; in fact, as long as ever the water is of a higher temperature than the surrounding air of the room. From these causes, the difference in the rate of cooling, of the two kinds of apparatus, will be nearly double what is here stated: so that a building warmed by hot water, will maintain its temperature, after the fire is extinguished, about six or eight times as long as it would do if it were heated with steam.

69. This is an important consideration wherever permanence of temperature is desirable; as, for instance, in hot-houses, conservatories, and other buildings of a similar description: and even in the application of this invention to the warming of dwelling-houses, manufactories, &c.; this property, which water possesses, of retaining its temperature for so long a time, and the very great amount of its specific heat, prevents the necessity for that constant attention to the fire, which has always been found so serious an objection to the general use of steam apparatus.

70. The velocity with which a pipe or any other vessel cools, when filled with a heated fluid, depends principally upon two circumstances—the quantity of fluid that it contains, relatively to its surface; and the temperature of the air by which it is surrounded; or, in other words, the excess of temperature of the heated body, above that of the surrounding medium. The subject of the radiation of heat, and the rate at which a heated body cools, under various circumstances, will be fully considered in another chapter. But for temperatures below the boiling point of water, and under such circumstances as we are now considering with regard to hot-water pipes, the velocity of cooling may be estimated simply in the ratio of the excess of heat, which the heated body possesses above the temperature of the surrounding air. The variation in the

rate of cooling, arising from a difference of the superficies to the mass, is, for bodies of all shapes, *inversely, as the mass divided by the superficies.* Therefore, the relative ratios of cooling, for any two bodies of different shapes and temperatures, is the inverse numbers obtained by dividing the mass by the superficies, multiplied by the direct excess of heat above the surrounding air; provided the temperature of the heated bodies be below 212°. Thus suppose the relative ratio of cooling be required, for two cisterns filled with hot water, one a cube of 18 inches, at the temperature of 200°; the other a parallelopiped, 24 inches long, 15 inches wide, and 3 inches deep, at the temperature of 170°; the surrounding air in both cases being 60°. Then, as,

	INCHES.		INCHES.		
The cube contains	5832,	divided by	1944,	the superficies	= 3· 0
The parallelopiped contains .	1080,	do.	954,	do.	= 1·13

The *inverse* of these numbers is, to call the cube 1·13, and the parallelopiped 3·0. Then multiply 1·13 by 140 (the direct excess of temperature of the cube), and the answer is 158·2: and multiply 3·0 by 110 (the direct excess of temperature of the parallelopiped), and the answer is 330·0. Therefore, the parallelopiped will cool, in comparison with the cube, in the proportion of 330 to 158, or as 2·08 to 1: so that if it requires two hours to cool the cube, a half, or a quarter, or any other proportional part of its excess of heat, the other vessel will

lose the same proportional part of its excess of heat in one hour.

71. It is evident that these different velocities of cooling, are quite independent of the effect that the respective bodies will produce, in warming a given space; for as the cube contains upwards of six times as much water as the other vessel, so it would warm six times as much air, if both vessels were of the same temperature. But if six of the oblong vessels were used, they would heat just the same quantity of air as the cube; but the latter would require rather more than $2\frac{1}{2}$ hours, to do what the oblong vessels would accomplish in one hour, supposing the temperature to be the same in both cases. In the previous example, the temperatures are supposed to be different: otherwise the relative ratio of cooling, of the two vessels, would have been as $2\frac{1}{2}$ to 1, instead of 2 to 1 as stated.

72. In estimating the cooling of round pipes, the relative ratio is very easily found; because the inverse number of *the mass divided by the superficies*, is exactly equal to the *inverse of the diameters*. Therefore, supposing the temperature to be alike in all,

If the diameter of the pipes be -	1.	2.	3.	4 inches.
The ratio of cooling will be - -	4.	2.	1·3.	1

That is, a pipe of 1 inch diameter will cool four times as fast as a pipe of 4 inches diameter; and so on with the other sizes. These ratios, multiplied

by the excess of heat which the pipes possess above that of the air, will give the relative rate of cooling when their temperatures are different, supposing they are under 212° of Fahrenheit: but if the temperatures are alike in all, the simple ratios given above, will show their relative rate of cooling, without multiplying by the temperatures. When the pipes are much above 212°, as, for instance, with the High Pressure system of heating, the ratio of cooling must be calculated by the rules given in the VIth Chapter.

73. The unequal rate of cooling of the various sizes of pipes, renders it necessary to consider the purpose to which any building is to be applied, that is required to be heated on this plan. If it be desired that the heat shall be retained for a great many hours after the fire is extinguished, then large pipes will be indispensable; but if the retention of heat be unimportant, then small pipes may be advantageously used. It may be taken as an invariable rule, that, in no case, should pipes of greater diameter than 4 inches be used, because, when they are of a larger size than this, the quantity of water they contain is so considerable, that it makes a great difference in the cost of fuel, in consequence of the increased length of time required to heat them. (See art. 156.) For hot-houses, green-houses, conservatories, and such like buildings, pipes of 4 inches diameter will generally be found the best; though

occasionally, pipes of 3 inches diameter may be used for such purposes, but never any of a smaller size. In churches, dwelling-houses, manufactories, &c. pipes of either 2 or 3 inches diameter will, perhaps, upon the whole, be found the most advantageous; for they will retain their heat sufficiently long for ordinary purposes, and their temperature can be sooner raised, and to more intensity, than larger pipes: and, on this account, a less number of superficial feet will suffice to warm a given space.

74. In adapting the boiler to a hot water apparatus, it is not necessary, as is the case with a steam boiler, to have its capacity exactly proportional to that of the total quantity of pipe which is attached to it: on the contrary, it is sometimes desirable even to invert this order, and to attach a boiler of small capacity to pipes of large size. It is not, however, meant, in recommending a boiler of small capacity, to propose also that it should be of small superficies; for it is indispensable that it should present a large surface to the fire, because, in every case, the larger the surface on which the fire acts, the greater will be the economy in fuel, and, therefore, the greater will be the effect of the apparatus.

75. The sketches of the boilers, figs. 13, 14, 15, 16, 17, & 18, and the section of the circular boiler, fig. 19, are several different forms which present

various extents of surface in proportion to their capacity.

Fig. 13.

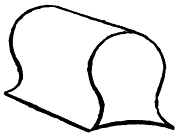


Fig. 14.

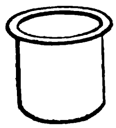


Fig. 15.

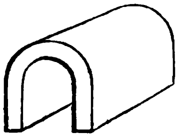


Fig. 16.

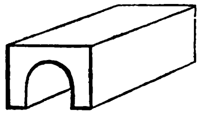


Fig. 17.

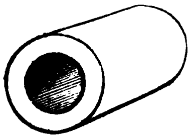


Fig. 18.

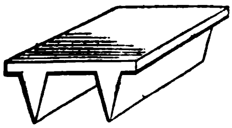
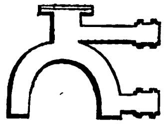


Fig. 19.



All except the two first, however, have but a small capacity, relatively to their superficies, compared with boilers which are used for steam. There is no advantage whatever gained by using a boiler which contains a large quantity of water; for, as the lower pipe brings in a fresh supply of water, as rapidly as the top pipe carries the hot water, off, the boiler is always kept absolutely full. The only plausible reason which can be assigned for using a boiler of large capacity, is, that as the apparatus then contains more water, it will retain its heat a proportionably longer time. This, though true in fact, is not a sufficient reason for using such boilers: for the same end can be accomplished,

either by using larger pipes, or by having a tank, connected with the apparatus, which can be so contrived, by being enclosed in brick, or wood, or some other non-conductor, as to give off very little of its heat by radiation, and yet to be a reservoir of heat for the pipes after the fire has been extinguished. If this tank communicates with the rest of the apparatus by a stop-cock, the pipes can be made to produce their maximum effect in a much shorter time than if this additional quantity of water had been contained in the boiler; and a more economical and efficient apparatus will be obtained. The circulation will likewise be more rapid from a boiler which contains but a small quantity of water; because the fire will have greater effect upon it, and will render the water which is contained in it, relatively lighter than that which is in the descending pipe.

76. In proposing the adoption of boilers of small capacity, however, it is necessary to accompany the recommendation with a caution against running into extremes; for this error has been the cause of the inefficiency of apparatus in many instances. The sketch, fig. 18, is an instance of this sort, in which an absurd extreme has occasionally been adopted. The contents of a boiler of this shape, sometimes does not exceed a couple of gallons, even when applied to a very large furnace; and though this boiler presents a large surface to the fire, the space allowed

for the water is so small, that the neutral salts and alkaline earths, deposited by the water which evaporates from the apparatus, contracts the water-way, already far too small, and effectually impedes the circulation, and also prevents the full force of the fire from acting on the water.

77. But perhaps the more immediate cause of failure, of this shaped boiler, arises in a different way. The quantity of water which it contains being so very small, and the heat of the fire, therefore, very intense upon it, a repulsion is caused between the iron and the water, and the latter does not receive the full quantity of heat. This extraordinary effect is not hypothetical: it has been proved to exist, by the most satisfactory experiments; particularly some which were made by the Members of the Franklin Institution of Pennsylvania. The repulsion between heated metals and water, they ascertained to exist, to a certain extent, even at very moderate degrees of heat; being appreciably different at various temperatures, below the boiling point of water. But, as the temperature rises, the repulsion increases with great rapidity; so that iron, when red hot, completely repels water, scarcely communicating to it any heat, except, perhaps, when under considerable pressure.

78. The boiler in question, however, seldom or never reaches the temperature of luminosity, though it is still sufficiently high to make a considerable

difference in the heating of the water. Added to this, the form of it prevents the full effect of the heat being communicated to the pipes: for the extreme smallness of the water way, prevents the rapid communication between the various parts, and therefore the upright, or flow pipe, receives its principal supply of heat from that portion of the boiler immediately underneath where it is fixed, instead of that equable communication of heat from all parts, which is the ordinary process in boilers of good proportions. There is likewise a probability that steam would form in this boiler, which would still farther interfere with the circulation of the water. But were the water way to be enlarged, all these inconveniences and probable causes of failure would proportionably decrease.

79. Though all these causes of inefficient action may not exist simultaneously, yet they may act at different stages of the working of the apparatus. But they all apply equally to every boiler, in which the rational limits of the surface, relatively to the size, have given place to wild chimeras and fanciful notions, not based on sound principles of philosophy.

80. It is obvious that the extent of surface which a boiler ought to expose to the fire, should be proportional to the quantity of pipe that is required to be heated by it: and it is not difficult to estimate these relative proportions with sufficient accuracy,

notwithstanding the various circumstances which modify the effect. Reckoning the surface which a steam boiler exposes to the fire, at 4 square feet, for each cubic foot of water evaporated per hour[1]; and calculating the latent heat of steam at 1000°; we shall find that the same extent of boiler surface, which would evaporate a cubic foot of water, of the temperature of 52°, into steam, of which the tension is equal to one atmosphere, would supply the requisite heat to 232 feet of pipe, 4 inches diameter, when its temperature is to be kept at 140° above that of the surrounding air. The following proportions for the surface which a boiler for a hot-water apparatus ought to expose to the fire, will be found useful.

Surface of Boiler exposed to the Fire.	4 in. Pipe.	3 in. Pipe.	2 in. Pipe.
3½ square feet, will heat	200 feet, or	266 feet, or	400 feet.
5½	300	400	600
7	400	533	800
8½	500	666	1000
12	700	933	1400
17	1000	1333	2000

81. A small apparatus ought, perhaps, to have rather more surface of boiler, in proportion to the

[1] The surface of a steam boiler which it is necessary to expose to the action of the fire, in order to evaporate one cubic foot of water per hour, varies from 2 to 10 square feet. according to the rapidity of the draught, and the intensity of the heat of the furnace. When the very small surfaces are used, mechanical means are requisite for blowing the fire.

length of pipe, than a larger one; as the fire is less intense, and burns to less advantage in a small, than in a large furnace. It depends, however, upon a variety of circumstances, whether it will be expedient to increase the quantity of pipe, in proportion to the surface of the boiler, beyond what is here stated; for although many causes tend to modify the effect, the above calculation will be found a good average proportion, under ordinary circumstances. The effect depends greatly upon the quality of the coal, the height of the chimney, the rapidity of draught, the construction of the furnace, and many other particulars; but it will always be found more economical, as regards the consumption of fuel, to work with a larger surface of boiler at a moderate heat, than to keep the boiler at its maximum temperature.

82. But beside all these causes that modify the effect, there is another that will greatly alter the proportions which may be employed. The data from which the calculation of the boiler surface is made, assumes the difference to be 140° between the temperature of the pipe and the air of the room which is heated; the pipe being 200°, and the air 60°. But if this difference of temperature be reduced, either by the air in the room being higher, or by the apparatus being worked below its maximum temperature; then, in either case, a given surface of boiler will suffice for a greater length of pipe. For

if the difference of temperature between the water and the air, be only 120°, instead of 140°, the same surface of boiler will supply the requisite degree of heat to $\frac{1}{6}$ more pipe; and if the difference be only 100°, the same boiler will supply above $\frac{1}{3}$ more pipe than the quantity before stated. It will, therefore, frequently occur in practice, that the quantity of pipe in proportion to a given surface of boiler, may be considerably increased beyond the amount which is given in the preceding Table: because, in forcing houses, for instance, the temperature of the air will always be above 60°; and in the warming of churches, workhouses, or other large buildings, the temperature of the water will generally be considerably below 200°—the pipe not being required to be worked at its greatest intensity — and, therefore, in both these instances, a larger proportion of pipe may safely be applied to a given sized boiler.

83. In order to estimate the quantity of surface, which is acted upon by the fire, an allowance must be made for the flues which circulate round the exterior of the boiler. Thus, suppose the boiler, fig. 15, to be 30 inches long; there will be about $8\frac{3}{4}$ square feet of surface exposed to the direct action of the fire: and suppose also there are four external flues, one on each side, and two on the top of the boiler, each being 12 inches wide; we may reckon that one half the effect is produced by these flues,

which would have obtained, had the direct action of the fire been employed on the like extent of surface; therefore the flues will be equal to 5 square feet of surface exposed to the *direct* action of the fire, making altogether $13\frac{3}{4}$ square feet, as the available heating surface of a boiler of this shape and size. This would be sufficient to heat about 800 feet of pipe 4 inches diameter, when the excess of its temperature above that of the surrounding air, is 140°, as before stated. A boiler of the same shape, and 24 inches long, has about 11 square feet of surface, when calculated by the preceding rule: a boiler 36 inches long, has $16\frac{1}{2}$ square feet of surface; and a boiler 42 inches long has 19 square feet of surface; the increase being directly proportional, in the simple ratio, to the length.

84. A circular boiler 30 inches diameter, like fig. 19, with a 9-inch circular flue round the outside, will expose, as nearly as possible, the same extent of surface as a boiler 30 inches long, of the shape last described; and therefore the one will be as effective as the other. The surface of other sizes of this shaped boiler can be easily calculated; but instead of varying in the simple ratio of the length or diameter, it will be found to be proportional to the *square of the diameter*, so that the proportion of surface increases more rapidly than in the arched boiler. Thus a circular boiler 24 inches diameter, has $8\frac{3}{4}$ square

feet of surface exposed to the fire; a 30-inch has $13\frac{3}{4}$ square feet; a 36-inch, $19\frac{3}{4}$ square feet; and a 42-inch, $26\frac{3}{4}$ square feet: the small sizes having less surface, and the large sizes having more, than the arched boilers of the shape of fig. 15.

CHAPTER V.

On the Construction and Dimensions of Furnaces.

85. Although the construction of the furnace for a hot-water apparatus, is a matter of some importance, it is not intended to enter here at any great length into the subject. To investigate the various inventions for furnaces which have been brought forward, would occupy much space; and such a course of inquiry appears to be unnecessary, because most persons who erect hot-water apparatus have had some experience in the construction of the ordinary descriptions of fire-work, and this, in fact, is all that is needful, or indeed desirable, for furnaces which are used for this purpose. The intense heat that is required for some descriptions of steam-engine furnaces is here unnecessary; but a moderate heat, economically applied, and the furnace constructed so that the fuel shall burn for several hours without attention is the object to be attained, and which is by no means difficult to accomplish, with a moderate degree of care.

86. The difficulties which attend the erection of furnaces for a hot-water apparatus, are comparatively trifling to those required for steam boilers. When a boiler is required to supply pipes for warming a building by steam, its size must be much larger than one for warming the same building with hot water. In the former case the capacity of the boiler must be considerably larger than that of the whole length of pipe: in the latter, its capacity may be half, or a quarter, or a tenth, or even a twentieth of the capacity of the pipes, without causing any diminution of the effect, provided (art. 76) this reduction in the size of the boiler, be not carried to an extravagant length.

87. In large steam boiler furnaces, in order to permit of the flue extending round the boiler, an extremely brisk fire and rapid draught are required, otherwise the heated and inflamed gases will not be of a sufficiently high temperature to impart heat to the boiler; but they will, in fact, before completing the circuit of the flues, and reaching the chimney, act as a cold body, and abstract heat from the boiler instead of imparting it. No such difficulty, however, occurs with boilers for hot water apparatus. A very moderate draught will suffice to carry the heated smoke, and inflamed gases, round a boiler of the comparatively limited size which is here required; and they will act as a heating body to a boiler of this kind, when at a temperature which would make

it act as a cold body to a steam boiler; because, in the latter case, the water is seldom of a less temperature than 220° to 230°, while, in the former, it is rarely above 180° to 200°.

88. Passing over then, as unnecessary for the present purpose, many ingenious forms which have been given to furnaces, it will be sufficient to describe the simple plan of construction which is most usually adopted.

The heat should be confined within the furnace as much as possible, by contracting the farther end of it, at the part called the throat, so as to allow only a small space for the smoke and inflamed gases to pass out. The only entrance for the air should be through the bars of the grate, and the heated gaseous matter will then pass directly upward to the bottom of the boiler, which will act as a reverbatory, and cause a more perfect combustion of the fuel than would otherwise take place. The lightness of the heated gaseous matter causes it to ascend the flue, forcing its passage through the throat of the furnace with a velocity proportional to the smallness of the passage, the vertical height of the chimney, and the levity of the gases, arising from their expansion by the heat of the furnace.

89. In this arrangement, the whole of the air which supports the combustion passes through the fire from below; and any air admitted at the furnace door, between the fuel and the boiler, reduces the

intensity of the heat. The only case where the admission of air above the fuel will be at all advantageous, is when coal which emits a vast quantity of flame is used, and which, therefore, contains a large quantity of hydrogen, and proportionably less oxygen, than Newcastle coal. Some of the Staffordshire and Scotch coals are of this description; and here, a portion of air admitted at the top of the fuel, will promote the more perfect combustion of the gaseous products of the coal. But, even in this case, less heat will be received by the boiler, in a given time, unless the air be warmed before it enters the furnace; for as air will not support combustion until it attains a temperature of from 900° to 1000°, of Fahrenheit, if a current of cold air passes between the fuel and the boiler, a certain portion of heat is required to raise the temperature of the air, which heat would, otherwise, have been received directly by the boiler.

90. In all ordinary cases, then, the greatest economy, as well as the greatest effect, will be produced by admitting air only through the ash-pit of the furnace; and the rapidity of combustion of the coal will depend upon the quantity of air admitted through the bars, and upon the velocity of its admission.

91. The quantity of coal which is required to be burnt in each particular furnace, must determine the area of the bars: and as this been ascertained

experimentally for steam boilers, it is merely necessary to reduce it to a standard suitable for a hot water boiler. Supposing the ordinary kind of furnace bars to afford about 30 inches of opening for the air, in each square foot of surface—measured as the bars are placed in the furnace, and allowing half-inch openings between the bars, when the bars themselves are about 1½ inches wide,—then the relative proportions between the area of the bars and the length of pipe should be as follows:—

Area of Bars.		4 in. Pipe.	3 in. Pipe.	2 in. Pipe.
75	Square inches will supply	150 feet, or	200 feet, or	300 feet.
100	. . . .	200 . .	266 . .	400 . .
150	. . . .	300 . .	400 . .	600 . .
200	. . . .	400 . .	533 . .	800 . .
250	. . . .	500 . .	666 . .	1000 . .
300	. . . .	600 . .	800 . .	1200 . .
400	. . . .	800 . .	1066 . .	1600 . .
500	. . . .	1000 . .	1333 . .	2000 . .

Thus, suppose there are 600 feet of pipe, 4 inches diameter, in an apparatus; then the area of the bars should be 300 square inches: so that 13 inches in breadth and 23 inches in length will give the requisite quantity of surface. But when it is required to obtain the greatest heat in the shortest time, the area of the bars should be increased, so that a larger fire may be produced[1].

[1] The above proportions for the area of the bars may, in many cases, be considerably reduced, particularly in the larger apparatus; because these proportions are calculated to give the maxi-

92. In order to make the fire burn for a long time without attention, the furnace should extend beyond the bars both in length and breadth; and the coals which are placed on this blank part of the furnace, in consequence of receiving no air from below, will burn very slowly, and will only enter into complete combustion when the coal which lies directly on the bars has burned away.

93. This plan of constructing furnaces is so well known as scarcely to need further description: it may, however, be observed, that the size of this blank, or dumb part of the furnace, should be comparative to the length of time the fire is required to burn; being larger or smaller in proportion as the fire is required to burn for a longer or a shorter period. As the maximum effect of the furnace is but seldom required, the register to the ash-pit door, and the damper to the chimney, must be used to regulate the draught, and thus limit the consumption of fuel.

94. The relative sizes of the furnace bars, and of the boiler, which have been stated in this and the preceding chapter, are all given with reference to certain lengths of pipe, which they will respectively heat. But to complete the calculations, it is necessary to ascertain the actual amount of heat which

mum effect, and in many cases this is never required: a less quantity of coal will, therefore, be used, and, of course, a less area of the bars will be sufficient.

a given quantity of pipe will afford, under the various circumstances which occur in the application of it to the warming of buildings of different descriptions. Before entering into this inquiry, however, it may be necessary to premise some observations on the general laws of heat.

CHAPTER VI.

General Laws of Heat—Radiation and Conduction—Law of Cooling in Air and other Gases—Ratio of Cooling—Law of Cooling by Radiation—Laws of Radiation—Effect of Surface on Radiation—Effect of Colour on Radiation—Capacity of Bodies for Caloric.

95. HOWEVER various are the methods by which artificial heat is distributed in the warming of buildings, they are all subject to certain conditions, which constitute the primary laws of heat; and in the present chapter some of these laws, which bear upon the subject before us, will be considered.

96. Heated bodies give off their caloric by two distinct modes,—radiation and conduction. These are governed by different laws; but the rate of cooling by both modes increases considerably in proportion as the heated body is of a greater temperature above the surrounding medium. This variation was long supposed to be exactly proportional to the simple ratio of the excess of heat; that is to say, supposing any quantity of heat given off in a certain time at a specified difference of temperature, at double that difference, twice the quantity of heat would be given off in the same time. This law was

originally proposed by Newton in the *Principia;* and, although rejected as erroneous by some philosophers, it was followed by Richmann, Kraft, Dalton, Leslie, and many others, and was usually considered accurate, until the masterly and elaborate experiments of M. M. Petit and Dulong proved that, though approximately correct for low temperatures, it becomes extremely inaccurate at the higher degrees of heat [1].

97. The cooling of a heated body, under ordinary circumstances, is evidently the combined effects of radiation and conduction. The conductive power of the air is principally owing to the extreme mobility of its particles; for, otherwise, it is one of the worst conductors we are acquainted with; so that, when confined in such a manner as to prevent its freedom of motion, it is a most useful non-conductor.

98. The proportion which radiation and conduction bear to each other, has in general been very erroneously estimated. Count Rumford considered the united effect, compared with radiation alone, was as 5 to 3; and Franklin supposed it to be as 5 to 2.

[1] As the present inquiry relates merely to *simple heat,* the recent important experiments of Nobili and Melloni on radiation by *luminous* hot bodies—which prove the existence of two distinct kinds of heating rays given off at the same time from the same body—do not affect the question; as it is only at a temperature amounting to luminosity, that these effects occur.

99. No such general law, however, can be deduced; for the relative proportions vary with the temperature, and with the peculiar substance or surface of the heated body. For, while *the cooling effect of the air by conduction is the same on all substances, and in all states of the surface of those substances,*—radiation varies materially, according to the nature of the surface.

100. The influence of the air, by its power of conduction, varies also with its elasticity or barometric pressure. The greater its elastic force, the greater also is its cooling power, according to the following law:—*When the elasticity of the air varies in a geometrical progression, whose ratio is* 2, *its cooling power changes likewise in a geometrical progression, whose ratio is* 1·366.

101. The same law holds with all gases, as well as with atmospheric air; but the ratio of the progression varies for each gas.

102. To show the relative velocities of cooling, at different temperatures, the following table, constructed from the experiments of Petit and Dulong, is given. The first column shows the excess of temperature[1] of the heated body above the sur-

[1] The temperatures *in this chapter* are all expressed in degrees of the Centigrade thermometer. As the zero of this thermometer is the freezing point of water, and from that to the boiling point of the same fluid is 100°;—in order to find the number of degrees of *Fahrenheit's* scale, which answers to any given temperature of the *Centigrade*, multiply the number of degrees of *Centigrade* by

rounding air; the second column shows the rate of cooling of a thermometer with a plain bulb; and the third column gives the rate of cooling when the bulb was covered with silver leaf. The fourth column shows the amount due to the cooling of the air *alone;* and by deducting this from the second and third columns respectively, we shall find what is the amount of *radiation*, under the two *different states of surface*, noticed at the top of the second and third columns.

Excess of Temperature of the Thermometer above that of the Air: Centigrade Scale.	Total Velocity of cooling of the naked Bulb.	Total Velocity of cooling of Bulb covered with Silver Leaf.	Amount of cooling due to Conduction of the Air alone.
260°	24·42	10·96	8·10
240°	21·12	9·82	7·41
220°	17·92	8·59	6·61
200°	15·30	7·57	5·92
180°	13·04	6·57	5·19
160°	10·70	5·59	4·50
140°	8·75	4·61	3·73
120°	6·82	3·80	3·11
100°	5·57	3·06	2·53
80°	4·15	2·32	1·93
60°	2·86	1·60	1·33
40°	1·74	·96	·80
20°	·77	·42	·34
10°	·37	·19	·14

9, and divide the product by 5; add 32 to the quotient thus obtained, and this sum will be the number of degrees of *Fahrenheit* required. As, however, in the above table, the temperatures given are only the *excess*, and not the absolute temperatures, the 32° to be added by this rule must be omitted.

103. Some very remarkable effects may be perceived by an inspection of the above table. It appears that the ratio of heat lost by contact of the air alone, is constant at all temperatures; that is, whatever is the ratio between 40° and 80°, for instance, is also the ratio between 80° and 160°, or between 100° and 200°. This law is expressed by the formula,—

$$v = n \, . \, t^{1 \cdot 233}$$

where t represents the excess of temperature, and n a number which varies with the size of the heated body. In the case represented in the foregoing table $n = 0 \cdot 00857$.

104. Another remarkable law is, that *the cooling effect of the air is the same, for the like excess of heat, on all bodies without regard to the particular state or nature of their surface.* This was ascertained by Petit and Dulong, in a series of experiments not necessary here to detail, but which abundantly prove the accuracy of the deduction[1].

105. By comparing the second and third columns in the above table, it will be immediately perceived that the loss of heat by *radiation* (deducting the cooling by conduction of the air given in the fourth column) varies greatly with the nature of the radiating surface; though, whatever be the nature of the

[1] Annals of Philosophy, vol. xiii.

surface, *the loss of heat follows the same law in all cases, though in a different ratio.*

106. It should be observed that, in this table, the second, third, and fourth columns show the number of degrees of heat which were lost per minute, by the body which was the subject of experiment; and, therefore, these numbers represent the *velocity* of cooling.

107. When the numbers in the last column are deducted from those in the second and third columns, the difference will show the loss of heat by *radiation*, for the plain and silvered bulb respectively; the fourth column being the loss by conduction of the air, which is the same for all surfaces. It will immediately be perceived, therefore, that the loss of heat by conduction and by radiation, bear no constant ratio to each other. But, while *conduction proceeds by a regular geometrical progression*, radiation follows another law, viz. *when a body cools in vacuo surrounded by a medium whose temperature is constant, the velocity of cooling, for excess of temperature in arithmetical progression, increases as the terms of a geometrical progression, diminished by a constant quantity.* This law is represented by the formula,—

$$V = m . a^{\theta} (a^{t} - 1)$$

where a is a constant quantity for all bodies $= 1{\cdot}0077$; t the excess of temperature of the radiating body; θ the temperature of the surrounding

medium; and *m* a coefficient which varies with the size and nature of the radiating body, to be determined for each particular case. It will likewise appear that, when we compare the *total cooling* of two different surfaces, the law is more rapid at low temperatures, and less rapid at high temperatures, for the body which *radiates the least*, in comparison with that which radiates with greater power.

108. But the cooling of a body by conduction of the air, differs from the effect of radiation in a remarkable manner in this particular;—that, while *the ratio of loss by conduction continues the same, for the same excess of temperature, whatever be the absolute temperatures of the air and heated body,—radiation increases in velocity, for like excess of temperature, when the absolute temperatures of the air and heated body increase.* The following table shows the law of *cooling by radiation*, for the same body at different temperatures:

Excess of Temperature of the Thermometer.	Velocity of Cooling when the surrounding medium is at the undermentioned Temperatures.			
	0°	20°	40°	60°
220°	8·81	10·41	11·98	——
200°	7·40	8·58	10·01	11·64
180°	6·10	7·04	8·20	9·55
160°	4·89	5·67	6·61	7·68
140°	3·88	4·57	5·32	6·14
120°	3·02	3·56	4·15	4·84
100°	2 30	2·74	3·16	3·68

It will be observed in this table, that, when the absolute temperatures of the surrounding medium and radiating body, are increased 20° of Centigrade, *the difference between their temperatures continuing the same,* the velocity of cooling is multiplied by 1·165, which is the mean of all the ratios in the above table, experimentally determined.

109. The total cooling of a body by radiation and conduction, then, we shall find to be represented, under all circumstances, by this formula,—

$$m \,.\, a^{\theta} \,(a^{t} - 1) + n \,.\, t^{b}$$

The quantities a and b are constant for all bodies and under all circumstances; the first being $= 1{\cdot}0077$ and the latter $= 1{\cdot}233$. The coefficient m will depend on the size and nature of the heated surface, as well as upon the nature of the surrounding medium. The coefficient n is independent of the absolute temperature, as well as of the nature of the surface of the body; but will vary with the elasticity and nature of the gas in which the body is plunged: t is the excess of temperature of the heated body, and θ the temperature of the surrounding medium.

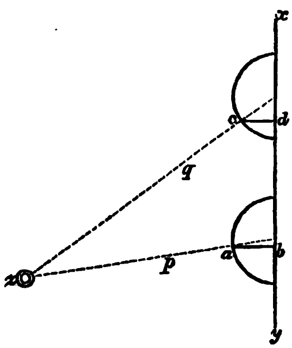
110. The fact, already adverted to, that the ratio of cooling of those bodies that radiate least, is more rapid at low temperatures, and less rapid at high temperatures, than those bodies that radiate

most, is perhaps one of the most remarkable of the laws of cooling. It was first deduced experimentally by Petit and Dulong, and it may be mathematically proved from their formulæ; but it is unnecessary here to enter into the investigation. It appears, however, that, when the total cooling of two bodies is compared, the law is more rapid at low temperatures, for the body which radiates least, and less rapid, for the same body, at high temperatures; though separately for conduction and for radiation, the law of cooling is, for the former, irrespective of the nature of the body, and for the latter, that all bodies preserve, at every difference of temperature, a constant ratio in their radiating power.

111. To revert to the first table in this chapter. We find the total cooling at 60° and 120° (of Centigrade), to be, about, as 3 to 7; at 60° and 180°, as 3 to 13; and at 60° and 240° as 3 to 21: whereas, according to the old law of Newton, they should have been respectively as 3 to 6; as 3 to 9; and as 3 to 12. But we find that the deviation increases greatly with the increase of temperature, and that when the *excess* of temperature of the heated body, above the surrounding air, is as high as 240° of Centigrade (432° of Fahrenheit), the real velocity of cooling is nearly double what it would appear to be by the old and inaccurate law, varying, however, with the nature of the surface.

112. But radiant heat is subject to other laws,

beside those we have yet considered. Rays of heat diverge in straight lines from every part of a heated surface, and likewise from extremely minute depths below the surface of hot bodies, being subject to the laws of refraction the same as light. The intensity of these rays *decreases as the square of the distance,* and the emission of the rays is greatest in a line perpendicular to the surface. The same law obtains here, also, as with light,—that the effect of the ray is *as the sine of the angle,* which it forms with the surface[1]. This *law of the sines,* first discovered by Leslie, suggests a practical caution connected with the subject before us,—namely, that the shape of the pipes used to warm a building, is not wholly unimportant; for, if flat pipes be used, and they be laid horizontally, the major part of the *radiated* heat from the



[1] Suppose *z* to be a body radiating heat; *x y* a plane surface, receiving two rays, radiated from *z*, represented by the dotted lines *p, q*. Then *a, b,* is *the sine of the angle,* the ray *p* forms, and *c, d,* is *the sine of the angle,* the ray *q* forms with the receiving surface. The heating effect is greater in proportion as *a b* is longer than *c d:* and if the ray proceeded in a straight line, perpendicular to the receiving surface, the effect would be the greatest possible.

The number of rays, radiated from any surface, is also found to be greatest in a line perpendicular to the surface of the radiating body.

upper surface, will be received on the ceiling, and, therefore, will produce but little beneficial effect. The loss sustained in this way will be greater in proportion to the higher temperature of the pipes, for it will be seen by the table at the beginning of this chapter, that the relative proportion which radiation bears to conduction, increases with the temperature: at the ordinary temperature of hot-water pipes, about one-fourth the total cooling is due to radiation.

113. The radiation of heat, we have already seen, is greatly either increased or diminished, according to the nature of the surface of the radiating body. Professor Leslie has given the following as the relative powers of radiation by different substances:

Lamp Black	100
Water (by estimate)	100
Writing Paper	98
Rosin	96
Sealing Wax	95
Crown Glass	90
China Ink	88
Ice	85
Red Lead	80
Isinglass	80
Plumbago	75
Thick Film of Oil	59
Film of Jelly	54
Thinner Film of Oil	51
Tarnished Lead	45
Thin Film of Jelly ($\frac{1}{4}$ of former)	38
Tin scratched with Sand-Paper	22
Mercury	20

Clean Lead	19
Iron, polished	15
Tin Plate	12
Gold, Silver, and Copper	12
Thin Laminæ of Gold, Silver, or Copper Leaf, on Glass	12

114. As it has been established by the experiments of M. M. Nobili and Melloni, as well as by other experimentalists, that *the radiating powers of surfaces, for simple heat, are in the inverse order of their conducting powers;* it follows that the above ratios of *radiating* power, will by no means be proportional to the total cooling of these respective bodies in air.

115. Professor Richmann, in order to ascertain the conducting power of metals, enclosed thermometers in hollow metallic vessels, which were heated by being immersed in boiling water, until every part had attained the same temperature. The heated vessels were then exposed to the air, and their times of cooling observed; the difference in this respect being considered as marking their *conducting power.* The metals which appeared to have the greatest power of *retaining* heat, were brass and copper; then iron and tin; and lead the least of all. The decrements of temperature in a given time being as follows:

Lead	25
Tin	17
Iron	11
Copper and Brass	10

The result of this experiment must, however, necessarily be inconclusive as regards conduction; because the rate of cooling, under such circumstances, would, if the bodies were extremely thin, be, in fact, exactly proportional to their radiating powers, which would prove nothing, *à priori*, as regards conduction. The result would also vary materially with the thickness of the metal.

116. The experiments of Ingenhausz and Dr. Ure, on the same subject, were on a totally different principle, and they vary but little from each other in the results. They coated the ends of rods of different metals with wax, and noted the time required to melt it, when the opposite ends were heated to a uniform temperature. Dr. Ure thus found silver, to be by far the best conductor; next copper; and then brass, tin, and wrought iron, nearly equal; then cast-iron and zinc; and lead he found by far the worst of all.

117. We might be led to conclude from all that precedes, that those metals which are the worst conductors, would be the most proper for vessels or pipes, for radiating heat; because, we find that the heat lost by contact of the air, is the same for all bodies, while those which *radiate most*, or are the worst conductors, give out more heat in the same time, than those bodies which *radiate least*, or are good conductors. Such would be the case if the vessels were *infinitely* thin; but as this is not pos-

sible, the slow conducting power of the metal, opposes an insuperable obstacle to the rapid cooling of any liquid contained within it, by preventing the exterior surface from reaching so high a temperature, as would that of a more perfectly conducting metal, under similar circumstances; thus preventing the loss of heat, both by contact of the air and by radiation, the effect of both being proportional to the excess of heat of the *exterior* surface of the heated body. If a leaden vessel were *infinitely* thin, the liquid contained in it would cool sooner than in a similar vessel of copper, brass, or iron: but the greater the thickness of the metal, the more apparent becomes the deviation from this rule; and, as the vessels for containing water, must always have some considerable thickness, those metals which are the worst conductors, will oppose the greatest resistance to the cooling of the contained liquid, although apparently in opposition to the result of the preceding experiments.

118. It is difficult on these grounds to account for the effect which lead paint has in preventing the free radiation of caloric, from bodies coated with it; because, in this case, the lead must be extremely thin, and ought, therefore, to increase the amount of radiation. The effect probably arises from the total change of state which the lead undergoes by its chemical combination with the carbonic acid, in the process of making it into white lead. Practically,

it is found to have an injurious tendency on the free radiation of heat from most bodies; varying, however, with their radiating powers. On a good radiator, its effect is the most injurious, on a bad one, less so: but its use should be avoided as much as possible, in all cases where the free radiation of heat is the object in view.

119. It is almost universally supposed that *colour* has a considerable influence on radiant heat, and also upon the absorption of heat—the two effects being similar and equal. Sir H. Davy, by exposing surfaces of various colours to the heat of the sun, proved experimentally (*Beddoe's Contributions*, p. 44), that the absorbing power of different colours was in this order;—black, blue, green, red, yellow, and white: black being the best, and white the worst absorbent. In this order then, we should expect to find the radiating powers of different colours, and that by painting a body of a dark colour, we should increase its power of radiation. This, however, is not the case. There are the strongest reasons for supposing that the absorption and radiation of *simple heat*;—that is, heat without light, or heat from bodies below luminosity,—are wholly irrespective of colour, and depend only upon the state or nature of the surface. Professor Powell considers (*Report on Rad. Heat*, p. 290), after an elaborate examination of all the phenomena attending the heat received from the sun, that there is no *simple*

radiant heat received by us from the sun's rays; and that the simple radiant heat, which no doubt is initially radiated from the sun, is absorbed by the atmosphere of that luminary, some small portion, perhaps, which escapes, being stopped in the higher regions of our own atmosphere. The experiment of Sir H. Davy, on the absorption and radiation of *solar* heat, by different colours, is not therefore applicable to the case of *simple heat*, or such heat as is given out by bodies below luminosity.

120. The Table, art. 113, evidently shows that the radiation of heat, of the intensity used in those experiments, bears no relation to colour. This temperature was about 200°, and was, therefore, *simple heat*. By this it appears, that lamp black, and white paper, are equal in power, while Indian ink is much less, and black lead still lower in the scale; though, as far as colour only is concerned, these last are nearly the same as lamp black. But Professor Powell has ascertained, (*Rep. on Heat*, p. 279.) that the radiation and absorption of *simple heat*, is not affected by colour, but only by the nature of the surface. He found that a thermometer bulb, coated with a paste of chalk, was affected even more than a similar one coated with Indian ink. So, likewise, Scheele found, that if two thermometers filled with alcohol, one red, and the other colourless, were exposed to the sun's rays, the coloured one would

rise in temperature much more rapidly than the other; but if they were both plunged into the same vessel of hot water, they rose equally in equal times.

121. We are fully justified, then, from these and analogous experiments, in drawing the conclusion, that *the radiation of* SIMPLE HEAT *is not influenced by the colour of the heated body.* Any difference which appears to obtain in this respect, is, therefore, solely referrible to the *nature* of the colouring substance.

122. The last of the laws of heat to which we shall allude, is one which is, perhaps, more remarkable than any that have been mentioned. It is that which is called *the capacity of bodies for caloric,* or, *the law of specific heat.* Though the principle is simple, the law is intricate; for it follows no constant ratio with the density, elasticity, or other known properties of matter; though Dr. Martin considered that the capacity of bodies for heat, was *nearly* in the inverse order of their conducting powers.

123. The same quantity of heat which will raise the temperature of a pound of water 1°, will raise the temperature of a pound of oil 2°, or a pound of mercury 23°; and almost every known substance possesses a capacity for caloric peculiar to itself. In a subsequent chapter, a practical application of this part of the laws of heat will be shown; but to follow it, in an extended manner, would lead to investiga-

tions not connected with the subject of this treatise, and only such of the laws of heat as are applicable to this inquiry, were purposed to be here investigated.

CHAPTER VII.

Experiments on Cooling.

124. From what has been stated in the preceding chapter, it is evident, that the velocity with which a heated body cools, depends upon various circumstances; and experiments are necessary, in order to obtain data for the calculations, which the known laws of heat enable us afterwards to make.

125. No experiments on cooling are extant, that appear to be suitable to the present purpose, except some that were made by Tredgold, and these are extremely erroneous in the application he has made of them. For he has neglected all considerations of the thickness of the body on which he experimented, and has therefore estimated, that the rate of cooling of a thin sheet-iron vessel, containing a heated fluid, is the same only as it would be, were it of any greater thickness. The same error also occurs in his experiments on the cooling of glass; and, consequently, all his conclusions on the disper-

sion of heat, are entirely incorrect. Another source of error lies in his having estimated the quantity of water which the vessels contained, at too large an amount, in order to allow for the specific heat of the vessel. Had the total quantity of heat that the vessel contained, been the object sought, this mode of calculation would have been correct; but it is not so, when the rate of cooling only, is the element required. The effect of each of these errors, is to make the rate of dispersion appear to be more rapid than the true velocity; and the result is, that in some of his experiments the errors amount to upwards of 16 per cent.

126. To ascertain by experiment the velocity of cooling, for a surface of cast-iron, I used a pipe 30 inches long, $2\frac{1}{2}$ inches diameter internally, and 3 inches diameter externally: the ends were closed, and the bulb of a thermometer was inserted about 3 inches into the water at one end, the temperature being alike in every part of the pipe. The exposed surface of the pipe was 287·244 square inches, and the quantity of water contained in it was 171·875 cubic inches. The rates of cooling were tried with different states of the surface: first, when it was in the usual state of cast-iron pipes, covered with the brown surface of protoxide of iron; next it was varnished black; and finally, the varnish was scraped off, and the pipe was painted white with two coats of lead paint. The following Table shows

the observed time of cooling, corrected and reduced to the same excess of temperature above the circumambient air.

TABLE of the Cooling of Iron.

Temperature of Room 67°. Maximum Temperature of Thermometer 152°.

Thermometer cooled,		Rusty Surface.		Black varnished Surface.		White Surface.	
from	to	Observed Time.	Calculated Time.	Observed Time.	Calculated Time.	Observed Time.	Calculated Time.
152°	150°	2′ 30″	2′ 21″	2′ 16″	2′ 16″	2′ 19″	2′ 24″
152	148	5 0	4 44	4 38	4 36	4 53	4 51
152	146	7 45	7 12	7 28	7 8	7 28	7 22
152	144	10 15	9 44	9 45	9 27	10 13	9 57
152	142	12 45	12 15	12 2	11 54	12 57	12 36
152	140	15 0	15 0	14 32	14 32	15 22	15 22

		Minutes.
The ratios of Cooling 1° are therefore,	Black Varnished Surface . .	1·21
	Iron Surface	1·25
	White Painted Surface . . .	1·28[1]

These ratios are in the proportion of 100, 103·3, and 105·7; but as the relative heating effect, is the inverse of the time of cooling, we shall find that 100 feet of varnished pipe, 103¼ feet of plain iron pipe, or 105¾ feet of iron pipe painted white, will each produce an equal effect.

[1] These ratios of cooling, it will be observed, are for pipes of 3 inches diameter: but the cooling of any other size can be calculated from the data here given.

127. In these experiments, it might have been expected to find greater differences between the effects of the various states of the surface, than appears really to obtain. The greatest difference only amounts to about $5\frac{1}{2}$ per cent., but it would probably be greater in proportion, with an increased thickness of the coating of paint.

128. To ascertain the effect of glass windows in cooling the air of a room, the following experiments were made, with a vessel as nearly as possible of the same thickness as ordinary window glass. The temperature of the room, in these experiments, was 65°; the thickness of the glass was ·0825 of an inch; the surface of the vessel measured 34·296 square inches, and it contained 9·794 cubic inches of water. The time in which this vessel cooled, when filled with hot water, is shown as follows:

TABLE of the Cooling of Glass.

Thermometer cooled, from	to	Observed Time of Cooling.	Calculated Time of Cooling.	Average Rate of the Observed Time of Cooling.
150°	140°	6′ 40″	6′ 54″	1·176° per minute, at an excess of 65° above the Temperature of the Air.
150	130	14 15	14 43	
150	120	23 30	23 40	
150	110	34 0	34 0	

129. From the average rate of cooling which is here given, the effect of glass in cooling the air of a

room may easily be calculated. As the specific heat of equal volumes of air and water[1], is as 1 to 2990, the above average will show that each square foot of glass will cool 1·279 cubic feet of air 1° per minute, when the temperature of the glass is 1° above that of the external air.

130. But by this we shall only find the effect of glass in a still atmosphere; and, therefore, to ascertain the cooling effect of external windows, when exposed to the action of winds, farther experiments are necessary.

131. In some researches of Leslie's, on the cooling power of wind, he used a bright metallic ball filled with hot water, and noted the time of cooling when it was exposed to wind at different velocities. The result he obtained was, that the cooling effect on the ball was very nearly in a direct ratio with the velocity. But it will be obvious, by referring to the experiments of Petit and Dulong, in the preceding chapter, that the relative cooling of heated bodies, when exposed to air moving at different velocities, must depend upon the nature of the surfaces. For while the quantity of heat which is abducted by the air, is proportional to the number of particles of air which pass over the heated body in a given time, the heat that is lost by radiation is not only independent of this effect, but the relative

[1] See Art. 139.

proportion of heat lost by radiation, differs for each particular substance. As the bright metal ball that Leslie employed in his experiments, would lose only an extremely small proportion of its heat by radiation, it might naturally be concluded that the rate of cooling would be nearly in a direct ratio with the velocity of the air. But with a surface of glass, the result must be very different, because the radiation is then very considerable; and, therefore, the total cooling will be much slower than the simple ratio of the velocity. For while a surface of glass of the temperature of 120°, and at an excess of 52° above the surrounding medium, loses about two-thirds of its heat by radiation, a bright metallic surface, of the same temperature, will only lose one-eleventh part of its heat by the same cause.

132. In the following experiments it appears that the cooling effect of wind, at different velocities, on a thin surface of glass, is very nearly as the square root of the velocity. In these experiments, the velocity of the air was measured by the revolution of the vanes of a fan; the temperature of the air was 68°; the time required to cool the thermometer 20° was noted for every different velocity, and the maximum temperature of the thermometer, in each experiment, was 120°. In still air it required 5′ 45″ to cool the thermometer this extent; and the following table shows the time of cooling by air in motion.

TABLE of the Cooling of Glass by Wind.

Velocity of the Wind, in Miles, per hour.	Times of Cooling the Thermometer 20°. From 120° to 100° of Fahrenheit.		
	Observed Time of Cooling.	Time, reduced to decimals of a minute.	Corrected Time; being the Inverse of the Square Root of the Velocities; in decimals of a minute.
3·26	2′ 35″	2·58	2·58
5·18	2 10	2·16	2·04
6·54	1 55	1·91	1·82
8·86	1 40	1·66	1·56
10·90	1 30	1·50	1·41
13·36	1 15	1·25	1·27
17·97	1 5	1·08	1·10
20·45	1 0	1·0	1·03
24·54	0 55	·91	·94
27·27	0 48	·81	·88

133. In consequence of the large quantity of glass in buildings used for horticultural purposes, the cooling effect of wind is of considerable importance. We see, however, that with an increased velocity, the cooling effect is considerably less in proportion, on glass than on metal: and it will be very much less on window-glass than even what is here stated; for, as glass is an extremely bad conductor of heat, the increased thickness which window-glass possesses over that which composes the bulb of a thermometer, will make a material difference in the quantity of heat that is lost by the abduction of the air, as there will be, in this case, a greater difference between the temperature of the

external and the internal surface. The cooling effect of wind is therefore not near so considerable on glass as is generally supposed; and it will probably be nearly one-half less on window-glass than what is shown by the preceding experiments.

CHAPTER VIII.

Heat by Combustion—Quantity of Heat from Coal—Specific Heat of Air and Water—Measure of Effect for Heated Iron Pipe—Cooling Power of Glass—Quantity of Pipe required to warm a given space—Quantity of Coal consumed—Time required to heat a Building—Facile Method of Calculating the Quantity of Pipe required in any Building.

134. Having in the preceding chapters investigated some of the fundamental laws of heat, we proceed to consider the particular effects practically deducible from them, so far as they relate to the subject of the present inquiry.

135. Very erroneous notions are entertained by many persons, as to the absolute quantity of heat contained in different substances. This subject has already been mentioned; and, in the present chapter we shall have occasion to apply this law of specific heat in several calculations.

136. Of the effect produced by the decomposition of combustible materials by fire, it may also be observed that erroneous notions prevail: for

the quantity of heat obtainable by the combustion of any substance, is not, as many persons appear to consider, illimitable, but is as fixed and determinate as any other of the laws of heat. The amount of it depends on the chemical composition of the particular substance; but this, however, is quite independent of any difference which obtains in the effect, in consequence of the perfection or imperfection of the apparatus in which the combustion is performed.

137. Though every kind of fuel differs in the quantity of heat that it affords, it is unnecessary, in such an inquiry as this, to regard any other than the ordinary description used for purposes similar to that we are now considering. The calculations will therefore be made only with reference to Newcastle coal of a good average quality.

138. It is stated by Watt, that 1 lb. of coal will raise the temperature of 45 lbs. of water from 55° to 212°. Rumford states the same quantity of coal will raise $36\frac{2}{10}$ lbs. of water from 32° to 212°; and Dr. Black has estimated that 1 lb. weight of coal will make 48 lbs. of water boil, supposing it previously to be at a mean temperature. These quantities, when reduced to a common standard, vary but little from each other. Watt's experiment of 45 lbs. of water being heated from 55° to 212°, is equal to $39\frac{1}{4}$ lbs. only, if heated from 32° to 212°: and this nearly agrees with Count Rumford's calcu-

lation; at least the variation is not more than might be expected from a slight difference in the quality of the coal. Dr. Black's estimate is as much in excess, over the experiment of Watt, as Rumford's is in defect: we may, therefore, take the average of these three experiments, which will give as a result, that 39 lbs. of water may be heated from 32° to 212° by 1 lb. of coal.

139. To ascertain the effect which a certain quantity of hot water will produce, in warming the air of a room, there appears to be no better method than that of computing from the specific heat of gases compared with water.

140. Every substance, it has before been observed, has its peculiar specific heat. Now, 1 cubic foot of water by losing 1° of its heat, will raise the temperature of 2990 cubic feet of air[1], the like extent of 1°: and by losing 10° of its heat, it will

[1] The specific heat of *equal weights* of water and air, by the experiments of Berard and Delaroche, is found to be as 1 to ·26669: but as the volume, or bulk, of an equal weight of atmospheric air is to water, as 827·437 to 1, we shall have ·26669 : 1 :: 827·437 = 3102, which is the number of cubic feet of air that has the same specific heat as 1 cubic foot of water. This, however, appears to be rather too high a calculation: for Dr. Apjohn, in a memoir recently published (*Rep. Brit. Sci. Assoc.* vol. iv.) gives the result of a new and accurate mode of determining the specific heat of permanently elastic fluids, by which he makes the specific heat of atmospheric air ·2767, when that of water is represented by unity. Therefore ·2767 : 1 :: 827·437 = 2990, which is the number given in the text.

raise the temperature of 2990 cubic feet of air 10°, or 29,900 cubic feet 1°, and so on.

141. In order to know the time it will take to heat a certain quantity of air, any required number of degrees, by means of hot water contained in metal pipes, we must calculate the effect from direct experiment; and, as the radiating and conducting powers of different substances vary considerably, it is necessary that the experiment be made with the same material as the pipes for which we wish to estimate the effect.

142. From the data obtained by experiments on the cooling of iron pipes[1], it appears that the water contained in a pipe 4 inches diameter, loses ·851 of a degree of heat per minute, when the excess of its temperature is 125° above that of the circumambient air. Therefore (by Art. 140), 1 foot in length, of pipe, 4 inches diameter, will heat 222 cubic feet of air 1° per minute, when the difference between the temperature of the pipe and the air is 125°.

143. To calculate the quantity of pipe that will be necessary to warm any particular room or building, and to maintain it at the required temperature, the heat lost by the necessary ventilation, and by the conducting and radiating power of the glass, and of any metallic substances used in the building, must be estimated.

144. The calculations of the quantity of air re-

[1] See Experiments on Cooling, Art. 126.

quired for ventilation, and the method of ventilating buildings, are considered in a subsequent chapter. (Chapter XI.) It is unnecessary, therefore, in this place to pursue the subject further than to state, that, in all public buildings, and rooms of dwelling-houses, a quantity of air equal to 3½ cubic feet for each individual the room contains, must be changed per minute, in order to preserve the wholesomeness and purity of the atmosphere.

145. The loss of heat in all buildings having any great extent of glass, we shall find to be very considerable. It appears by experiment[1] that 1 square foot of glass will cool 1·279 cubic feet of air, as many degrees per minute, as the internal temperature of the room exceeds the temperature of the external air: that is, if the difference between the internal and the external temperature of the room be 30°, then 1·279 cubic feet of air will be cooled 30° by each square foot of glass, or, more correctly, as much heat as is equal to this, will be given off by each square foot of glass; for, in reality, a very much larger quantity of air will be affected by the glass, but it will be cooled to a less extent. The real loss of heat from the room will therefore be what is here stated.

146. But though this effect is only in a still atmosphere, as intense cold is seldom or never accom-

[1] Experiments on Cooling, Art. 129.

panied with high winds [1], no additional allowance needs be made for this cause, provided we calculate sufficiently low for the external temperature. For the highest winds are generally about March and September: and the average temperature of the former month is 46°, and the latter 59½°. The greatest diurnal variation of the thermometer is 20° in March, and 18° in September, so that the average temperature of the nights will be 36° in March [2], and 50° in September. But we shall find (Art. 152), that when the external atmosphere is at 36°, the quantity of pipe required to warm a building to 65°, is only about one-half of what would be necessary were the external air at 10°: therefore, if we calculate that the external temperature will be 10°, when we estimate the quantity of pipe required to warm a building which is to be used during the night, and that it will be 25° or 26°, externally, in the case of such buildings as are only wanted to

[1] That intense cold is rarely accompanied by high winds, is matter of common experience. The obliquity of the sun's rays on the higher latitudes of the Northern hemisphere, when near the time of the winter solstice, prevents the atmosphere of those places which are distant from the Tropics from receiving any considerable quantity of heat; and, therefore, the air being all of nearly equal density, there is but little tendency to aerial currents in the lower strata.

[2] These temperatures are for the neighbourhood of London. In March, 1837, the night temperature, obtained by a register thermometer, only averaged 31·1°, which is nearly 5° lower than has been known for many years.

be warmed during the day, the required heat can then be maintained, even during the time of high winds[1].

147. But in such situations as are very much exposed to high winds, it will be prudent to calculate the external temperature from *zero*, or even below that, according to circumstances; and, in very warm and sheltered situations, a less range in the temperature will be sufficient: a local knowledge of the situation will therefore be necessary to guide the judgment in particular cases.

148. The difference between the cooling effect of glass which is glazed in squares, and that which is lapped, is very trifling in those buildings where the air contains much moisture. This is the case in hothouses, where the plants are constantly steamed, and therefore, for such buildings, no farther allowance should be made on this account, for loss of heat[2].

[1] By reckoning the external air at the above temperatures, the wind may have a velocity of from 20 to 30 miles an hour, without producing any diminution of the internal temperature; for it is probable that the cooling effect of wind on window glass, is not above one half as much as appears by the experiments, Art. 132.

[2] The calculations of the specific heat of air, given in the note, Art. 140, are only for dry air. If the temperature be at 60°, and the air saturated with moisture, then the same quantity of heat will only raise the temperature of 2967 cubic feet of this saturated air any given number of degrees, which would have raised 2990 cubic feet of dry air to the like temperature. This 2967 cubic feet of saturated air will contain 67 cubic inches of water; and this quantity of water will absorb as much heat during its conversion into vapour, as would raise the temperature of 115,922 cubic

But in skylights of dwelling-houses, in consequence of the greater dryness of the atmosphere, the heated air will escape through the laps of the glass in greater quantity, in proportion as less vapour is condensed on the surface. The height of the skylight will also make a considerable difference in the velocity of the escape of air through the laps, as it depends upon the same principles which have been explained (Art. 33), as governing the motion of water; the increased velocity being relatively as the height and the difference of temperature between the internal and external air.

149. In making an estimate of the quantity of glass contained in any particular building, the extent of surface of the wood work must be carefully excluded from the calculation. This is particularly necessary in buildings used for horticultural purposes, where, from the smallness of the panes, the wood-work occupies a considerable space. The readiest way of calculating, and sufficiently accurate for ordinary purposes, is to take the square surface

feet of air 1°. This is equal to the entire heat that 46 feet of pipe, 4 inches diameter, will give off in ten minutes, when its temperature is 140° above that of the air. The glass will, however, cool much less of this saturated air, than of dry air, for the mixture of air and vapour has greater *specific heat* than dry air. With lapped glass the loss of heat will be less with saturated than with dry air, because the vapour when condensed upon the glass, will run down and nearly fill up the crevices between the laps, and effectually prevent the escape of the air, and thereby avoid the loss of heat.

of the sashes, and then deduct one-eighth of the amount for the wood-work. In the generality of horticultural buildings, the wood-work fully amounts to this quantity: but in some expensively finished conservatories, &c., it is considerably less, and therefore the allowance must be made accordingly. When the frames and sashes are made of metal, the radiation of heat will be quite as much, from the frame as from the glass; therefore, in such cases, no deduction must be made.

150. Some loss of heat will likewise arise from imperfect fitting of doors and windows. In these cases the circumstances vary very considerably; but in the majority of instances, no allowance is necessary for these sources of loss of heat, the external temperature of the air having been reckoned sufficiently low to supersede the necessity of any farther deduction.

151. From the preceding calculations, the following corollary may be drawn:—the quantity of air to be warmed *per minute*, in habitable rooms and public buildings, must be $3\frac{1}{2}$ cubic feet for each person the room contains, and $1\frac{1}{4}$ cubic feet for each square foot of glass; and for conservatories, forcing houses, and other buildings of this description, the quantity of air to be warmed *per minute*, must be $1\frac{1}{4}$ cubic feet for each square foot of glass which the building contains. When the quantity of air required to be heated, has been thus ascertained, the

length of pipe which will be necessary, may be found by the following

RULE:—Multiply 125 by the *difference* between the temperature at which the room is purposed to be kept, when at its maximum, and the temperature of the external air; and divide this product by the *difference* between the temperature of the pipes, and the proposed temperature of the room: then, the quotient thus obtained, when multiplied by the number of cubic feet of air to be warmed *per minute*, and this product divided by 222, will give the number of feet in length, of pipe 4 inches diameter, which will produce the desired effect.[1]

When the pipes which are to be used, are 3 inches diameter, then the number of feet of 4-inch pipe, obtained by this rule, must be multiplied by 1·33, which will give the length of 3-inch pipe: or to obtain the quantity of 2-inch pipe, the length of

[1] Let p be the temperature of the pipe, and t the temperature the room is required to be kept at; then $\frac{125}{p-t} = x$, which will represent the number of feet of pipe that will warm 222 cubic feet of air 1° per minute, when $p-t$ is different to the proportions given in art. 142. If d represents the difference between the internal and the external temperature of the room, and c the number of cubic feet of air which are to be warmed per minute, then $x \cdot \frac{d \cdot c}{222} = F$, will be the number of feet of pipe 4 inches diameter, which will warm any quantity of air per minute, according to the calculations art. 142.

The rule given in the text has been arranged in such a manner, that it may be worked without decimals.

pipe 4 inches diameter, obtained by the rule, must be multiplied by 2; the length required of 3-inch pipe, being one-third more than 4-inch, and the length of 2-inch pipe being double that of the 4-inch, when the temperatures are the same in all.

152. By the following table, however, even the simple calculations given in this rule may be dispensed with. The table shows the quantity of pipe 4 inches diameter, which is required to heat 1000 cubic feet of air *per minute*, any number of degrees. The temperature of the pipes is assumed to be 200° of Fahrenheit; this being the most usual temperature at which they can be easily maintained. But according to the length of pipe which is heated by one boiler, the temperature will sometimes be greater and sometimes less than this estimate, the temperature of the water being generally higher when only a small quantity of pipe is used. When the quantity of air to be warmed *per minute* is greater or less than 1000 cubic feet, the proper quantity of pipe will be found, by multiplying the length given in the table, by the number of cubic feet of air to be warmed *per minute*, and dividing that product by 1000.

TABLE of the Quantity of Pipe, 4 inches diameter, which will heat 1000 Cubic Feet of Air per minute, any required Number of Degrees : the Temperature of the Pipe being 200° Fahrenheit.

Temperature of external air.	Temperature at which the room is required to be kept.									
Fahrenheit's Scale.	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°
10°	126	150	174	200	229	259	292	328	367	409
12°	119	142	166	192	220	251	283	318	357	399
14°	112	135	159	184	212	242	274	309	347	388
16°	105	127	151	176	204	233	265	300	337	378
18°	98	120	143	168	195	225	256	290	328	368
20°	91	112	135	160	187	216	247	281	318	358
22°	83	105	128	152	179	207	238	271	308	347
24°	76	97	120	144	170	199	229	262	298	337
26°	69	90	112	136	162	190	220	253	288	327
28°	61	82	104	128	154	181	211	243	279	317
30°	54	75	97	120	145	173	202	234	269	307
Freezing point } 32°	47	67	89	112	137	164	193	225	259	296
34°	40	60	81	104	129	155	184	215	249	286
36°	32	52	73	96	120	147	175	206	239	276
38°	25	45	66	88	112	138	166	196	230	266
40°	18	37	58	80	104	129	157	187	220	255
42°	10	30	50	72	95	121	148	178	210	245
44°	3	22	42	64	87	112	139	168	200	235
46°		15	34	56	79	103	130	159	190	225
48°		7	27	48	70	95	121	150	181	214
50°			19	40	62	86	112	140	171	204
52°			11	32	54	77	103	131	161	194

*** To ascertain by the above table, the quantity of pipe which will heat 1000 cubic feet of air per minute ;—find, in the first column, the temperature corresponding to that of the external air, and in one of the other columns find the temperature of the room : then, in this latter column, and on the line which corresponds with the external temperature, the required number of feet of pipe will be found.

153. If the building which it is designed to warm, is required to be used only during the day, the air, in this part of the country at least, is

scarcely likely to be below 25°; but if,—as for a forcing-house, for instance,—it is required to be warmed both day and night, then, perhaps, 10° will not be too low to calculate from, or 22° below freezing. Suppose, now, a forcing-house has to be kept at 75° in the coldest weather,—which we will suppose to be 10° of Fahrenheit,—then by the Table we find, under the column 75°, and on the line with 10° for external temperature, the quantity 292, which is the number of feet in length, of pipe 4 inches diameter, that are required to heat 1000 cubic feet of air per minute, the proposed number of degrees. Any other difference of temperature may be found in the same way.

154. The quantity of coal necessary to supply any determinate length of pipe, is easily ascertained from the data given in Art. 138. After the water in the pipes is heated to its maximum, the quantity of coal consumed is, obviously, just what is required to supply the heat given off from the pipes. Now, by Art. 126 we find, that when pipes, four inches diameter, are 146·8° hotter than the air of the room, the water contained in them loses exactly 1° per minute of its heat. By Art. 138 we find that 1 lb. of coal will raise the temperature of 39 lbs. of water 180°; therefore, as 100 feet in length of 4-inch pipe contains exactly 544 lbs. of water, it will require 13·9 lbs. of coal to raise the temperature of this quantity of water 180°. If, therefore, the water loses 1° of heat per minute, or 60° per hour, this

quantity of coal will supply 100 feet in length of pipe, for three hours, if its temperature continues constant with regard to the air of the room. On this principle the following Table has been constructed. The temperature of the pipe is assumed to be 200°: then, knowing the temperature of the room, if we take the *difference* between the temperature of the pipe and that of the room,—by looking in the Table for the corresponding temperature, we shall find under it the number of pounds weight of coal which will be required per hour, for every 100 feet in length of pipe, in order to maintain the stated temperature. Thus, suppose the pipe to be 4 inches diameter, and its temperature 200°, while the room is at 75°; then, under the column headed 125°, (which is the difference between these two temperatures), we find 3·9 lbs. as the quantity required per hour for every 100 feet of pipe. The quantities stated in the Table are given in pounds and tenths of a pound.

TABLE of the Quantity of Coal used per Hour, to heat 100 Feet in length of Pipe of different Sizes.

Diameter of Pipe, in Inches.	Difference between the Temperature of the Pipe and the Room, in Degrees of Fahrenheit.														
	150	145	140	135	130	125	120	115	110	105	100	95	90	85	80
4	4·7	4·5	4·4	4·2	4·1	3·9	3·7	3·6	3·4	3·2	3·1	2·9	2·8	2·6	2·5
3	3·5	3·4	3·3	3·1	3·0	2·9	2·8	2·7	2·5	2·4	2·3	2·2	2·1	2·0	1·8
2	2·3	2·2	2·2	2·1	2·0	1·9	1·8	1·8	1·7	1·6	1·5	1·4	1·4	1·3	1·2
1	1·1	1·1	1·1	1·0	1·0	·9	·9	·9	·8	·8	·7	·7	·7	·6	·6

155. It should be here observed, that an apparatus will not always consume the same quantity of coal: in fact, it will but seldom require so much as the Table shows, because that is the calculation for the maximum effect. Suppose the quantity of pipe in a room has been accurately calculated, in order to maintain the temperature at 75° when the external air is at 30°; the consumption of coal, for pipes of 4 inches diameter, will then be 3·9 lbs. per hour for every 100 feet of pipe. But should the external temperature now rise to 40°, 77 feet of pipe would produce the same effect as 100 feet would in the former case: therefore, the pipe must be heated to a lower temperature, and only 3 lbs. of coal would be used, instead of 3·9 lbs. As much coal, therefore, as would supply 77 feet of pipe at the maximum temperature, would suffice for 100 feet at this reduced temperature. The quantity of fuel which is consumed will, therefore, be continually subject to variation, as it will alter with the temperature of the external atmosphere: and in general, the average quantity of coal required, will be about one-third less than the amount given in the Table.

156. It may not be amiss to estimate the length of time which will be necessary to heat a building with pipes of different sizes. This will, of course, depend upon many circumstances: nevertheless, an approximation may be made to the average time required. Suppose the pipe is to be heated to the

temperature of 200°, the water being at 40° before lighting the fire; then the maximum temperature of the building will be attained with

4-inch Pipes, in about $4\frac{1}{2}$ hours
3-inch Pipes, in about $3\frac{1}{2}$ hours
2-inch Pipes, in about $2\frac{1}{2}$ hours.

But if a larger quantity of coal than that given by the Table be used; if the surface of the boiler be much increased in proportion to the length of pipe; if the quantity of pipe used be excessive; or the temperature of the external air is higher than the estimated amount; then, in each of these cases, the time required for heating will be less. But if, on the contrary, the required temperature be not attained in the time given above, then, either too small a quantity of pipe, too small a surface of boiler, or too small a quantity of coal has been used.

157. It should, however, be observed, that although the *maximum* temperature will not be reached, at an average, in less time than is above stated; still, the required temperature will very often not take longer than half or two-thirds of this time, to be attained: because the quantity of pipe being always apportioned to meet the case of extreme cold, when the external temperature is above that extreme limit, the pipe, by being superabundant, will warm the same space in a shorter time.

158. Various circumstances may, however, interfere to diminish the effect of the apparatus; such, for instance, as damp walls,—particularly if the building is new—excess of ventilation, &c. The effect of damp walls in reducing the apparent power of an apparatus is very considerable, in consequence of the great quantity of heat which is necessary to evaporate the moisture. For it will require as much heat to vaporise one gallon of water from the walls of a building, as would raise the temperature of 47,840 cubic feet of air 10°. The true power of an apparatus can, therefore, never be ascertained, unless the building be perfectly dry. The same cause, though in a much less degree, becomes operative in buildings which are only occasionally warmed; and a longer time will always be necessary to heat such places, than those that are in constant use.

159. For estimating the quantity of pipe which is required to warm any building, rules of a much more facile character, though, at the same time, much more loose and inaccurate than those which have been already given, may easily be constructed; but they will answer sufficiently well in many common cases. Thus, in churches and very large public rooms, which have only about an average number of doors and windows, and moderate ventilation, by taking the cubic measurement of the room, and dividing the number thus obtained by 200, the quotient will be *the number of feet in length, of pipe*

4 *inches diameter*, which will be required to obtain a temperature of about 55° to 58°. For smaller rooms, dwelling-houses, &c. the cubic measurement should be divided by 150, which will give the number of feet of 4-inch pipe. For greenhouses, conservatories, and such like buildings, where the temperature is required to be kept at about 60°, dividing the cubic measurement of the building by 30, will give the required quantity of pipe; and for forcing-houses, where it is desired to keep the temperature at 70° to 75°, we must divide the cubic measurement of the house by 20; but if the temperature be required as high as 75° to 80°, then we must divide by 18, to obtain the number of feet of 4-inch pipe. If the pipes are to be 3 inches diameter, then we must add one-third to the quantity thus obtained; and if 2-inch pipes are to be used, we must take double the length of 4-inch pipe.

160. The quantity of pipe estimated in this way will only suit for such places as are built quite on the usual plan; but for others,—and indeed in all cases where it can be done,—the method given in the former part of this chapter should be employed. (Art. 151 and 152.)

161. It should here be mentioned, that the calculations for the quantity of pipe required for horticultural buildings, have been made with regard to the most economical mode of effecting the desired object. Some of the most successful horticulturists,

however, have adopted the plan of using a much stronger heat in their forcing-houses, and allowing, at the same time, a much greater degree of ventilation than usual. This plan is stated to produce a finer fruitage; but it will only be obtained at an increased cost in the apparatus, and by a larger expenditure of fuel. Where economy is not required, it may, perhaps, be desirable to adopt this plan; and then the quantity of pipe which is used, must be proportionally increased above the estimates which are given in this chapter.

CHAPTER IX.

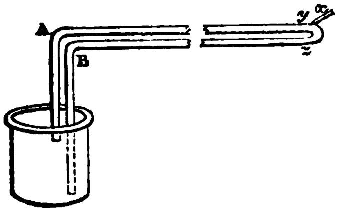
Various Modifications of the Hot-water Apparatus—Kewley's Syphon Principle—The High Pressure System—Eckstein and Busby's Circulator or Rotary Float, &c.

162. UNDER the common and generic term of "hot-water apparatus," various plans have been brought forward by different inventors, which, though essentially different in some of their features from those that have been already described, are, nevertheless, merely modifications of the general principles that have been explained. In the present chapter, some of these peculiar modifications of the invention will be investigated: and it will appear, that the original principles of all are the same, but that other of the fundamental laws of Nature are here brought into action, conjointly with those that we have already examined, and give rise to an apparent diversity of operation.

163. The first notable invention of this sort

which shall be mentioned, is Kewley's syphon principle. The sketch, fig. 20, shows this apparatus in its simplest form. The boiler is open at the top, and the two pipes dip into the water; the pipe A descending only a very short distance below the surface, and the pipe B reaching nearly to the bottom of the boiler. A small flexible metal pipe, *x*, is attached to the highest part of the pipes. To this an air pump is connected, and the air in the pipes being exhausted by this means, the atmospheric pressure forces the water up the pipes and fills them completely. This avoids the necessity of having a reservoir of water higher than the top of the boiler; for it is well known, that the usual atmospheric pressure is capable of raising a column of water in a vacuum, to about 30 feet in height, varying, however, with the degree of pressure shown by the barometer.

FIG. 20.



164. The water in the longer pipe, B, will acquire a preponderance of weight over that in the pipe A, even if it be at first of an equal temperature and density; because the pipe B only receives the particles of hot water which rise immediately under its base, while the other receives the heat from all parts of the bottom as well as the sides of the

boiler; the water on the top being hotter than that at the bottom. But as soon as the water circulates through the pipes, it parts with its heat, and the whole length of the pipe B will then be colder than the pipe A, and the water will descend through B with greater force.

165. In consequence of the long pipe B being surrounded by the hot water in the boiler, the water, while descending through it, receives a small portion of heat, which lessens the difference of temperature of the two pipes, and reduces the velocity of the circulation. It appears probable, therefore, that additional velocity of circulation would be gained by placing the descending pipe, B, outside the boiler, and attaching it to the side in the same manner as the return pipe in fig. 5. The principal inconvenience attending this would be the difficulty of stopping the ends of the two pipes, A and B, which is now done by a simple contrivance of two plates screwed moveably to their base. This completely stops the water when necessary,—the ends of the pipes being turned true to the plates, to make them water tight,—and by reversing the action of the pump, attached to the pipe *x*, the soundness of the joints can then be ascertained. A leaky joint is difficult of detection by any other means, as there is no emission of water from it in the usual way; and as the only immediate consequence of a leaky joint is the immission of air, it is not observable except

by its stopping the circulation of the water, which occurs, by the air accumulating and cutting off the connection of the water between the two pipes.

166. If this plan of having the return pipe placed outside the boiler were found to increase the motive power of the apparatus, an advantage would be gained in all those cases where the pipes are required to pass under a doorway; because, in all such cases, the boiler must be set much lower beneath the level of the floor, in the same manner, and for the same reasons, which have already been explained with regard to the common hot-water apparatus. But by increasing the motive power, a less height would be sufficient; and it would therefore prevent the inconvenience sometimes found to attend this particular form of the apparatus, arising from the great depth the furnace is required to be sunk beneath the level of the pipes, in consequence of the very large size of the boiler which is generally used.

167. A singular fact is connected with this invention, which deserves notice, because it arises from a philosophical principle, which, in some other instances, has been applied in a most useful manner; though, with this invention, it is rather disadvantageous than otherwise. It has already been stated, that the height to which the water will rise in a vertical column, by the atmospheric pressure, is about 30 feet above the boiler. Supposing this to be the extreme limit to which the water will ascend,

if the pipe be elongated in the least above this, a vacuum will be formed, similar to that at the top of a barometer, and the water at the top of the pipe will, in this case, be *without any pressure.* But if, instead of 30 feet, the pipe be continued upwards only 15 feet, then the pressure on the water, in the upper part of the pipe, will be $7\frac{1}{2}$ lbs. on the square inch,—or half the usual atmospheric pressure;—and so on for other heights. Now, the boiling point of all liquids varies with the pressure. Water boils at 212°, under the mean pressure of 15 lbs. per square inch; but by reducing the pressure, it boils at a lower temperature; so that, at half the mean pressure of the atmosphere, it boils at about 186°. Suppose now that the pipes just described, rise 30 feet above the boiler, the water at the top will boil at the temperature of 161°, and will form steam in the upper part of the pipe; and this, by its great expansion, will force the water down and overflow the boiler, or the supply cistern. For at the ordinary pressure of the atmosphere, steam occupies about 1700 times as much space as the water from which it is formed, and still more at a diminished pressure; its expansion being inversely as the pressure. When the pipes rise to other heights above the boiler than that described above, the boiling points will be as follows,—

at 5 feet high, the boiling point will be	203°
10	195°
15	186°

20	feet high, the boiling point will be	178°
25	. . . .	169°
30	. . . .	161°

therefore the water in the boiler must always be kept below these temperatures, according to the height to which the pipes ascend [1].

168. This peculiarity, which applies only to pipes on the syphon principle, is more a philosophical fact than a practical difficulty; for the water can generally be kept at a temperature sufficiently low for any ordinary height that is required. And, in fact, the boiling point will generally be higher than the temperatures here stated; because a small portion of air always remains in the pipes, which increases the pressure on the water, and makes the boiling point higher than the calculated amount.

169. This form of the apparatus answers the intended purpose extremely well, and has been

[1] These calculations are made by Wollaston's rule for his thermometric barometer. But this rule, although accurate at moderately small differences of pressure, is undoubtedly erroneous at considerable reductions of pressure. Professor Robison estimates the boiling point of water, *in vacuo*, at only 88°, instead of 161° which Wollaston's rule shows; and it is probable that the relative proportion between the pressure and the boiling point is in a logarithmic ratio, instead of the common arithmetical proportion of Wollaston's rule. This, in fact, is found to be the case at temperatures above 212°. But it is probable that, in the present case, Wollaston's rule will give a more accurate result than the other; because, as the vacuum in the pipes cannot be at all perfect, the boiling points will be much higher than the calculated temperature; perhaps even higher than stated in the text.

extensively applied in practice: and it exhibits not only a considerable knowledge of the principles of science, but also great ingenuity in their application.

170. The next invention which we shall consider, is, the High Pressure hot-water apparatus. This apparatus consists of a coil of small iron pipe, built into a furnace, the pipe being carried from the upper part of the coil, and continued round the room or building which is to be warmed, forming a continuous pipe when again joined to the bottom of the coil. The diameter of this pipe is one inch externally, and half an inch internally. A large pipe, of about $2\frac{1}{2}$ inches diameter, is connected, either horizontally or vertically, with the small pipe, and is placed at the highest point of the apparatus. This large pipe, which is called "the expansion pipe," has an opening near to its lower extremity, by which the apparatus is filled with water, the aperture being afterwards secured by a strong screw; but the expansion pipe itself cannot be filled higher than the opening just named. After the water is introduced, the screws are all securely fastened, and the apparatus becomes completely hermetically sealed. The expansion pipe, which is thus left empty, is calculated to hold about $\frac{1}{12}$ as much water as the whole of the small pipes; this being necessary in order to allow for the expansion that takes place in the volume of the water when heated, and which, otherwise, would inevitably burst the pipes, however

strong they might be. For the expansive force of water is almost irrepressible, in consequence of its possessing but a very small degree of elasticity; and the increase which takes place in its volume, by raising the temperature from 39° (the point of greatest condensation) to 212, is equal to about $\frac{1}{23}$ part of its bulk, and at higher temperatures the expansion proceeds still more rapidly [1].

171. The temperature of these pipes, when thus arranged, can be raised to a very great extent; for being completely closed, and all communication cut off from the atmosphere, the heat is not limited, as usual, to the point of 212°, because the steam which is formed is prevented from escaping, as it does in the common form of hot-water apparatus. The most important consideration respecting it, however, is the question as to its safety; for most persons are aware that steam, when confined beyond a certain point of tension, becomes extremely dangerous; and in this apparatus the boundary of what has hitherto been used in other cases is very far exceeded.

172. On the first introduction of this plan, it was usual to make the coil consist of one-fourth part of the total quantity of pipe which was used in the apparatus; and it was considered that when this proportion was observed, the heat of the pipes could not be raised so high as to endanger them by bursting.

[1] See Table IV.

But in practice this has not always proved a preventive to accident, even when the proportion which the coil bears to the radiating surface is much smaller than is here mentioned.

173. The average temperature of these pipes is stated to be generally about 350° of Fahrenheit. But, a most material difference of temperature occurs in the several parts of the apparatus; the difference, amounting sometimes to as much as 200° or 300°. This arises from the great resistance which the water meets with, in consequence of the extremely small size of the pipes, and also from the great number of bends, or angles, that of necessity occur, in order to accumulate a sufficient quantity of pipe. In these angles, the bore of the pipe, already extremely small, is still farther reduced, which causes the water to flow so very slowly, that a great portion of its heat is given out, long before it has circulated round the building which is to be warmed. The temperature of the coil, however, is what we must ascertain, if we wish to know the pressure this apparatus has to sustain, and thence to judge of its safety: for by a fundamental law of hydrostatics, whatever is the greatest amount of pressure on any part of the apparatus, must also be the pressure on every other part.

174. Now the temperature of this apparatus is found to vary, not only with the intensity of the heat of the furnace, but also with the proportion which the surface of the coil bears to the surface of

the pipe which radiates the heat. In some apparatus, if that part of the pipe which is immediately above the furnace be filed bright, the iron will become of a straw colour, which proves the temperature to be about[1] 450°. In other instances it will become purple, which shows the temperature to be about 530°; while, in some cases, it will become of a full blue colour, which proves that the temperature is then 560°. By this means the pressure on the pipes may be known; for as there is always steam in some part of the apparatus, the pressure may be calculated as soon as the temperature is ascertained. By referring to Table I. we shall find that a temperature of 450° produces a pressure of 420 lbs. per square inch, while a temperature of 530° makes the pressure 900 lbs.; and when it reaches 560°, the pressure is then 1150 lbs. per square inch.

175. Those who are acquainted with the working of steam engines, are aware that a pressure of 45 to 48 lbs. per square inch is considered as the maximum for high pressure boilers: but we see that in this apparatus the pressure varies from ten times to twenty-four times that amount. And it will also be borne in mind, that, in consequence of the extremely small quantity of water used in these pipes, the slightest increase in the heat of the furnace will cause an immediate increase in the pressure on the

[1] See Table VI.

whole apparatus. For it appears, by a reference to the Table last mentioned, that if the temperature of the pipes be increased 50° above the amount before stated, the pressure will be raised to 1800 lbs. per square inch; and by increasing the temperature 40° more, the pressure will be immediately raised to 2500 lbs. per square inch; so that any accidental circumstance, which causes the furnace to burn more briskly than usual, may, at any moment, increase the pressure to an immense amount.

176. The pipes which are used for this apparatus are stated to be proved with a pressure of 2800 lbs. per square inch[1]. This is very probable: for as wrought iron, of the best quality, requires a longitudinal strain of 55,419 lbs. to break a bar one inch square; so the force necessary to break a wrought iron pipe, of one-inch diameter externally, and half-an-inch diameter internally, would be 13,852 lbs., which is equal to 8822 lbs. per square inch on the internal diameter. But, on account of the expansive force of the water and steam being transverse to the grain of the iron, and, also, in consequence of the welded joint of the pipe not being so strong as the solid metal, these pipes will not bear any thing like the calculated amount of pressure. It is evident, however, that no ordinary force can burst them;

[1] As pipes are always proved when they are cold, this does not at all show the strain they will bear when heated. On this subject see the following note.

but as this casualty does sometimes occur, this great strength of the materials proves the impossibility of regulating the temperature in hermetically sealed pipes, so as to keep the expansive force of the steam within even this immense limit.

177. Although this description of apparatus has been erected by many different individuals, possessing various degrees of mechanical knowledge, and severally performing their work with different degrees of excellence, much uniformity appears in the result, in those cases where failure has occurred. From a comparison of a number of cases where accidents have happened to apparatus erected on this system, more than one-half have arisen from the bursting of the coil, notwithstanding the increased size of the expansion pipe renders this apparently the weakest part of the apparatus; the relative strength of pipes, with the same thickness of metal, being inversely as their diameters.

178. The cause of the explosions occurring principally in the coil, is owing to the iron becoming weaker in proportion as its temperature is raised; so that, as the pressure increases, the iron decreases in strength to resist the strain[1]. Another circum-

[1] The temperature of maximum strength for cast iron has been estimated at about 300° ; but the "Committee on the Explosion of Steam Boilers," appointed by the Franklin Institution, consider that the maximum for wrought iron is somewhat higher. After the temperature of maximum strength is once passed, the decrease in the strength of wrought iron is very rapid: at a red

stance also tends to produce the same effect. It is found, on breaking one of these pipes after it has been used for some time in or near the fire, that the iron has lost its fibrous texture, and that it presents a crystallized appearance, similar to what is known as "cold short iron." This singular change in the texture of iron has been noticed in other instances. Mr. Lowe (*Brit. Sci. Rep.* 1834), has found that wrought iron at a red heat, exposed to the steam of water for a considerable time, becomes crystallized; and in many other instances also, even without the presence of steam, the same effect has been observed. It is not easy to account for this phenomenon on any of the known chemical properties and habitudes of iron; but, whatever may be the cause, the effect undoubtedly is to weaken the tenacity and cohesive strength of the metal.

179. But we shall find that, enormous as the pressure appears to be with which these pipes are proved, it is quite inadequate to the working pressure which they sometimes have to resist. It has been ascertained that the relative strength of wrought iron at 300° and at 800° is about as 6 to 1; therefore, if the temperature of the iron, above 300°,

heat, or about 800°, it is only one-sixth of the maximum; so that in a range of less than 500° it loses five-sixths of its strength. The maximum strength of copper, on the contrary, is at a very low temperature; for the strength increases with every reduction of temperature, down to 32°, which is the lowest that has been tried.—*Journal of the Franklin Institution*, 1836.

increases in an arithmetical progression whose ratio is 100, the relative strength will decrease in an arithmetical progression whose ratio is 1; so that we shall have—

Temperature,	300°	400°	500°	600°	700°	800°
Strength,	6	5	4	3	2	1

Now, according to this relative decrement of strength, when the working pressure on pipes which are heated to 600°, is 1600 lbs. per square inch[1], the iron at that temperature being reduced in strength one half from its maximum, the proof pressure, when the pipes are cold, should be 3200 lbs. per square inch. By the same rule we shall find, that if the pipes are to be used at higher temperatures, the proof pressure, when cold, should be as follows:—

Temperature of Pipe when in Use.	Proof Pressure when cold, in lbs. per Square Inch.
650°	5,500
700°	9,900
750°	18,600

And if we farther consider, that, after the iron has been in use for some time, at a high temperature, it loses its fibrous texture, and becomes, in its crystallized state, only equal in strength to cast iron, which is, at an average, less than one half the

[1] See Steam Pressures, Table 1.

strength of wrought iron[1], it will appear that the proof pressure, when cold, for pipes which are to be used in this kind of apparatus, ought, in fact, to be double the amount here stated, and therefore, very much greater than the amount to which they are actually proved. But the pressure which is here stated is obviously more than the iron could sustain; and hence the cause of the pipes bursting after they have been in use for some considerable time, if they happen accidentally to get heated to very high temperatures.

180. The question has sometimes been asked, What would be the effect on this apparatus if the expansion pipe were to be filled with water, as well as the small circulatory pipe? The almost immediate consequence would be the bursting of the pipes; for scarcely any thing can resist the expansive power of water. The force necessary to resist its expansion, is equal to that which is required for its artificial condensation. Now, at the temperature of 386°, water expands rather more than $\frac{1}{12}$ of its bulk; and, to condense water this extent (Note, Art. 19), requires a pressure of 27,104 lbs. per square inch: therefore, in an apparatus containing 800 feet of pipe, the bursting pressure, at this temperature, on the circulating and expansion pipe

[1] Professor Barlow, On the Strength of Materials.—*Brit. Sci. Rep.* vol. ii.

together[1], would be 417,022,144 lbs.! But as nothing could resist such a force as this, the apparatus would burst before it reached even a fractional part of this immense amount. For if the pipes were filled completely full of cold water, without allowing any room for expansion, and if they were then hermetically sealed, as before described, by increasing the temperature of the water only about 60°, the expansion of the water would cause a pressure of 2000 lbs. per square inch, on every part of the apparatus, reckoned by the internal measurement.

181. The assertion has often been made, that the heated fluid contained in an apparatus constructed on this plan, will not scald, even if the pipes should chance to burst, because *high-pressure steam*, it is well known, is not injurious in this respect. But this is quite a mistaken notion; for high-pressure hot water will scald, though high-pressure steam will not; and the fluid which would issue through any fissure that might occur in these pipes, could only be partially converted into steam, unless its temperature were at least 1200°. This is obviously impossible; but were it the case, the water would be all converted into steam the instant that it issued from the pipe. The reason that high-

[1] The steam being an expansive force from within, the pressure is only exerted on the inside measurement of the pipes.

pressure steam does not scald, is in consequence of its capacity for *latent* heat being greatly increased by the high state of rarefaction it instantaneously assumes when suddenly liberated: this lowers its *sensible* temperature, and causes it to abstract heat from every thing that it comes in contact with. The scalding effect of high-pressure hot water, on the contrary, when suddenly projected from a pipe or boiler by explosion, will always be the same, whatever its temperature, while confined within the pipe, may be; for the instant it is liberated, a portion of it is converted into steam, and the remainder sinks to the temperature of about 212°.

182. Among the advantages which have been supposed to arise from the use of this invention, it has [been] imagined that, in consequence of the quantity of water which the pipes contain being so small, the consumption of coal would be less with this than with any other description of hot-water apparatus. We have seen, however, (Art. 154), that the quantity of coal which is used, is in proportion to the heat that is given off in the room that is warmed; and a reference to the Table, Art. 154, will show that the size of the pipe makes no difference in the consumption of coal per hour,— the only difference being in the length of time required to warm the water in the first instance. But there will, on the contrary, be a greater expenditure of fuel in this apparatus, in consequence of

the coil affording less surface for the fire to impinge against, than would be obtained by using a boiler. In addition to this, the colder any surface may be, when exposed to the action of a fire, the more heat will it receive in a given time; therefore, as the heat of these pipes is nearly three times as great as that of a boiler, there must be a considerable waste of fuel from this cause.

183. In consequence of the intense heat of these pipes, it is sometimes found that rooms which are heated by them, have the same disagreeable and unwholesome smell which results from the use of hot-air stoves and flues. In reality, the cause is the same in both cases; for it arises partly from the decomposition of the particles of animal and vegetable matter that continually float in the air, and partly from a change which atmospheric air undergoes, by passing over intensely heated metallic surfaces[1]. From some experiments recorded in the *Philosophical Transactions* of the Royal Society, made with a view of ascertaining the effect produced on the animal economy by breathing air which has passed through heated media, it appears that the air which has been heated by metallic surfaces of a high temperature, must needs be exceed-

[1] The exact nature of this change which the air undergoes has not been ascertained; but whatever be the chemical alteration which occurs, a physical change undoubtedly takes place, by which its electrical condition is altered.

ingly unwholesome. A curious circumstance is related in reference to these experiments, which is illustrative of this fact:—

"A quantity of air which had been made to pass through red-hot iron and brass tubes, was collected in a glass receiver, and allowed to cool. A large cat was then plunged into this factitious air, and immediately she fell into convulsions, which, in a minute, appeared to leave her without any signs of life. She was, however, quickly taken out and placed in the fresh air, when, after some time, she began to move her eyes, and, after giving two or three hideous squalls, appeared slowly to recover. But on any person approaching her, she made the most violent efforts her exhausted strength would allow, to fly at them, insomuch that in a short time no one could approach her. In about half an hour she recovered, and then became as tame as before."

184. The high temperature of these pipes, and the intensity at which the heat is radiated from them, has sometimes been urged as an objection against this invention, when applied to horticultural purposes; because, any plants which are placed within a certain distance of them, are destroyed. Although, no doubt, this effect really takes place, it can be easily avoided with proper care; for, as radiated heat decreases in intensity *as the square of the distance*, it only requires that the plants should be placed farther off from these pipes than from

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those which are of a lower temperature. In comparing the effect of two different pipes, if one be *four* times the heat of the other,—deducting the temperature of the air in both cases,—the plants must be placed *twice* as far off from the one as from the other, in order to receive the same intensity of heat from each. The only inconvenience, therefore, is the loss of room, which, in some cases, may not be of much importance. But a more serious objection by far, appears to lie in the inequality of temperature which any building heated by these pipes must have, in consequence of their being so very much hotter in one part than in another. This difference of temperature between various parts of the same apparatus, has already been stated to amount, in some cases, to as much as 200° or 300°, varying, of course, with the length of pipe through which the water passes. From what has been stated in Chapter IV., it will also be observed that, owing to the smallness of these pipes, this kind of apparatus cools so rapidly when the fire slackens in intensity, that the heat of a building which is warmed in this manner, will be materially affected by the least alteration in the force of the fire, instead of maintaining that permanence of temperature which is so peculiarly the characteristic of the hot-water apparatus, with large pipes.

185. These inconveniences and objections against the apparatus, however, are of but secondary im-

portance in comparison with the question which exists respecting its security. But as there are no means of regulating the temperature in hermetically sealed pipes, so there can be none for limiting the pressure which they sustain: and it is only by methods far too refined for general use, that the real amount of the expansive force can be ascertained. An apparatus which to all appearance, therefore, is perfectly safe at any given time of inspection, may in a few minutes afterwards have the pressure so much increased by adventitious circumstances, as to render it extremely dangerous, particularly if its management be confided to unskilful hands: and each day that it is used must add to its insecurity, in consequence of the pipes which form the coil continually becoming thinner by the action of the fire.

186. This invention undoubtedly exhibits great ingenuity; and, could it be rendered safe, and its temperature be kept within a moderate limit, it would be an acquisition in many cases, in consequence of its facile mode of adaptation. Its safety would perhaps be best accomplished by placing a valve in the expansion-pipe, which, from its large size, would be less likely to fail of performance than one which was inserted in the smaller pipe. If this valve were so contrived as to press with a weight of 135lbs. per square inch, the temperature of the pipes would not exceed 350° in any part: the pressure would then

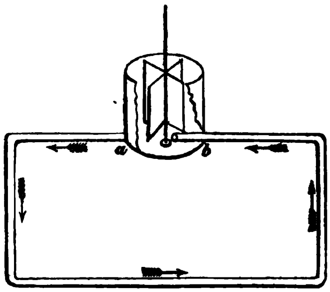
be nine atmospheres, which is a limit more than sufficient for any working apparatus, where safety is a matter of importance.

187. An apparatus of a totally different character from the preceding, follows next to be described. It is an invention which, at first, appears to be singularly at variance with the general principles that have been laid down in this treatise; but, however its mode of action may at first appear to differ from the laws which have been explained, it is certain that, if they are derived from the laws of Nature, they must act equally, at all times, and under all circumstances; for the operation of the physical laws can never be suspended, though they may be occasionally neutralized by a superior antagonist force. In the case of two opposing forces, the resulting action is proportional to their difference of power; but when the antagonist force is removed, each will act according to its own peculiar laws.

188. This is the case with the invention now to be described. By it, hot water is made to *descend* to any required depth below the boiler,—apparently in opposition to the law of gravity,—while the cold water will *ascend*, though of greater specific weight.

189. Eckstein and Busby's Patent Circulator, or Rotary Float, is an invention by which *centrifugal force* is made to overcome the *force of gravity*, in the circulation of hot water. The boiler, which is either open or closed at the top, has a pipe *a*

Fig. 21.



attached to its circumference, which is carried in any direction, either downwards or around the room to be warmed, and finally returns into the boiler, and ends exactly in its centre, as shown at *b*, in the annexed figure.

190. The float, or circulator, has motion given to it by means of a fly, similar to a smoke-jack, which is placed in the chimney and is turned by the smoke of the fire that is used to heat the boiler,—the float being fixed on centres, and revolving freely in the boiler. The centrifugal force imparted to the water by the rapid rotation of this float, causes it to rise higher at the periphery than in the centre of the boiler; and the velocity with which the float moves, determines the extent of this deviation from the level. The end of the pipe *b*, being in the centre, is then under a less pressure, or head of water, than the pipe *a*,—the former being, by its position, removed from the greater pressure at the sides, which is caused by the centrifugal force imparted to the water by the float, which acts on the pipe *a*, placed at the circumference.

191. Suppose now the velocity of rotation to be such as to impart a centrifugal force sufficient to raise the water *one inch* higher at the circumference

than in the centre,—there will then be a pressure of $246\frac{1}{2}$ grains per square inch, upon the pipe *a*, more than upon the pipe *b*, supposing the temperature of the water to be about 180°. This additional pressure will allow the water in the pipe *a* to descend 42 feet below the boiler, if it does not lose more than 6° of heat before it returns back again to the boiler through the pipe *b*: if it lose 10°, then it will only descend $25\frac{1}{2}$ feet, and so on for other temperatures. Now, as a pipe 4 inches diameter loses ·817 of a degree of heat per minute, when its temperature is 120° above that of the room (Art. 126); this pipe may be of as great a length as the distance through which the water will flow in seven minutes and a half, in the first case, or twelve minutes in the second.

192. The length of pipe through which the water will circulate in the abovementioned times, will depend upon the depth to which it descends below the boiler. In this apparatus, the shorter the distance through which the water flows, the greater is the rapidity of circulation;—an effect which is the reverse of what occurs in the common form of hot-water apparatus. In general, the circulation is here very rapid; but the distance through which the water will travel is more limited than with the common plan of circulation. For, suppose the water to be raised, by the centrifugal force, one inch higher at the periphery than at the centre of the boiler,

and that it descends 42 feet; if the water in the pipe lose 6° of heat during its transit, the circulation will then be extremely slow; because, by the Table, Art. 26, we find that the difference of weight between two columns of water 42 feet high, and 6° difference of temperature, is 242 grains per square inch on the area of the pipe, which is within 4 grains of the weight of the one-inch additional height of the water in the boiler. But if the difference between the temperature of the two pipes be only 4°, then the difference between the weight of the two columns will be 160 grains per square inch of the area of the pipe; and, by Art. 33, we shall find that this will give a velocity of 81 feet per minute, so that the pipe may in this case be about 400 feet long. But if the water only lose 3° of heat during its transit through the pipes, then (by Art. 33) its velocity will be 100 feet per minute, provided it descends only 42 feet below the boiler; and therefore, the pipe may be about 350 feet in length. If the depth of the descent below the boiler be only one half the amount above mentioned,—or 21 feet instead of 42,—then the length of pipe through which the water will circulate, will be just double the amount that has been stated for the several differences of temperature.

193. These calculations are all made for pipes of 4 inches diameter; but if smaller pipes be used, the distance through which the water will circulate, will

be less; because, as the quantity of heat lost in a given time by different sized pipes, is *as the inverse of their diameters*, so also will be the distance that the water will flow, if the velocity of its motion be the same[1].

194. If greater velocity be given to the fly-wheel and float, the centrifugal force, and the height of the water at the circumference of the boiler, will both be increased; and the distances to which the pipes can be carried, may then likewise be extended.

195. By using a close boiler instead of an open one, a range of pipes may be taken upwards, which will act on the common plan of circulation, while another range of pipes may proceed from the bottom, and act on the principle which has here been explained. In this case the centrifugal force, of which the additional height at the circumference of the boiler is merely the index or measure of effect, will still be of equal power, provided the velocity of the float continues the same; and the water will therefore descend to the same extent as before. The spindle of the float must, in this latter case,

[1] It will be observed from what has been stated respecting the common plan of circulation, that the whole of these effects are exactly the reverse of what there occurs. In that, the greater the difference of temperature between the pipes, the more rapid the circulation: in this, the circulation is more rapid in proportion as the pipes are nearer to the same temperature. In the former, the circulation is more rapid when the pipes are moderately small: in the latter, the larger the pipe, the greater the velocity of circulation.

pass through a stuffing box on the top of the boiler, or some other contrivance to answer the same purpose must be adopted.

196. This invention, which is a happy application of dynamical principles, to overcome one of the most constant of Nature's laws, by the development of an antagonist force, has hitherto been but little used. It is, however, clearly capable of being efficiently applied, in those cases where the same object cannot be accomplished by any of the more simple means which have been previously described.

197. Various other forms of hot-water apparatus have been proposed by Price, Fowler, Weeks, Smalley, Saul, and others; and several of these have been made the subject of patents. But none of them appear to merit particular notice, as they present no new features in the *principle;* the chief object which the inventors have aimed at, being some fancied advantages by adopting peculiar shapes either of the boiler, or the radiating surfaces. Some of these inventions, however, are decidedly erroneous on scientific principles, and, of course, objectionable in practice. One of these plans may be mentioned, in which the boiler consists of a number of cast-iron pipes, 1½ or 2 inches diameter, which are fastened together in the form of an arch. These pipes are not only liable to crack by the unequal expansion to which they are subject, but they must also become stopped up in a short time, by the sediment from the

water, which will, of course, prevent the circulation. Another plan, now nearly, if not wholly, laid aside, consisted in making the flow pipe of about ten or twelve times the area of the return pipe; a contrivance, which, by lessening the rapidity of circulation, prevented the full effect of the heat in the boiler from becoming available.

198. The advantage which may be derived from any peculiar forms of the apparatus, must depend entirely upon the purpose for which it is required. No rule can be laid down which is applicable to every case. But in all places where a long continuance and uniformity of temperature are required, the form of the pipes, tanks, boxes, or other radiating surfaces, must be such as to afford only a small surface to a large body of water; while, on the contrary, where these objects are not matters of importance, the radiating surface may advantageously be increased, relatively to the quantity of water. This may be accomplished either by using smaller pipes, or by altering the shape of the radiating surfaces; and a variety of ways of effecting this object, will naturally suggest themselves to an ingenious mind.

CHAPTER X.

Summary of the Subject, and General Remarks.

199. HAVING in the preceding Chapters arranged, under distinct heads, the various remarks on the principles of warming by the circulation of hot water, it may here be desirable to bring under general review, the principal facts which it has been the object of this work to explain. There are, besides, many minor points connected with the invention, that could not conveniently be brought under notice in any of the foregoing divisions, under which the subject has been treated, but which, nevertheless, may be found useful to those who are investigating its principles and application.

200. A correct knowledge of the cause of circulation of the water, it has already been observed, is absolutely necessary to the successful application of this invention in many of its more complicated arrangements. Some estimate must be formed of

the amount of the motive power possessed by an apparatus of this sort, otherwise it will be impossible to ascertain what will be the result of any particular position or determinate length of the pipes, in many peculiar cases; as, for instance, in such forms of apparatus as figures 10, 11, and 21. It is also necessary, in order to make provision for the escape of the air from an apparatus of this kind, to have some knowledge of the laws which regulate the motion of fluids, in order to ascertain where the air will lodge, and why it should accumulate in one place rather than another. No circumstance connected with the subject requires greater caution than this. In every part of the apparatus where an alteration of the level occurs, a vent for the air must be provided; because, from the extreme levity of air compared with water (Art. 13), it is impossible that the air can ever descend, so as to pass an obstruction lower than the place where it is confined. Thus, in fig. 7, if the air accumulate in the pipe between A and *e*, it is evident that a vent at C, although it would take off the air from *g*, *h*, and from C, D, could not receive any portion of that which is confined between A, *e*, or between *e*, *f*, because, in that case, it must *descend* through the pipe *e*, *f*, before it could escape. The principle is the same in all cases, however large, or however small the descent may be: and the accidental misplacing of a pipe in the fixing, by which one end may be made a little

higher then the other, will as effectually prevent the escape of air through a vent placed at the lower end, as though the deviation from the level were as many *feet*, as it may, perhaps, be *inches*. It is, however, impossible to give multiplied examples of this part of the subject, for probably no two instances, precisely similar, may occur; but it deserves the most serious attention in following out its practical consequences, for many failures have arisen from its neglect.

201. When any particular obstructions are required to be overcome, in consequence of numerous alterations in the level of the pipes; when the pipes are required to descend below the boiler; or, in short, when any other variation from what may be considered as the usual form and arrangement of the apparatus may be desirable, it is essentially necessary to have some data on which to found a calculation as to what will be the practical result of the required deviation; for no partial experiment of a tentative character, or even the effect shown by a miniature model, will give any thing like an accurate idea of what will be the result, when the experiment is made on a large scale. The reason of this is obvious. It has been shown, that the greater the distance through which the water flows, the greater does the motive power become, in consequence of the water being colder in the return pipe relatively to the flow pipe. This will, therefore, prevent partial experi-

ments,—that is, working models, exhibiting only a particular portion of the whole apparatus,—from being conclusive: and, with a miniature model, although the decreased time and distance of transit, are compensated by the reduced size of the pipe exerting a greater cooling power on the water, the friction being much greater in small than in large pipes, the velocity will be reduced in a very sensible degree, and the results rendered wholly inconclusive. In general, the successful working of a miniature model, will be conclusive that the experiment on a larger scale will perform still better; but the failure of the model will be no proof that the larger apparatus will not be successful.

202. The data on which calculations may be founded, sufficiently accurate for this purpose, have been given in the preceding Chapters; and by following out, in detail, the rules which are there given, a tolerably accurate judgment may be formed, as to the result that may be expected, under almost every form of the apparatus that may be adopted.

203. The quantity of heating surface required to warm any given space, has been fully discussed in Chapter VIII., as likewise the consumption of fuel, and other matters connected with this part of the subject. The fact, that the consumption of fuel to warm a given space, is irrespective of the size of the pipes, and the quantity of water they contain, is, perhaps, not in accordance with the generally

received opinion; but, nevertheless, it will be found correct, in so far, at least, as regards the maintaining the temperature of a building at a given standard, after the water in the apparatus is heated. But by using moderately small pipes, a saving both of time and fuel will be effected; because, the smaller the quantity of water employed, the less fuel will it require to heat it to a given temperature. For the greater expenditure of fuel which occurs in consequence of using large pipes, is merely owing to the larger body of water requiring a longer time to heat, than would a less quantity; but, when once the temperature of the pipes has attained its equilibrium, it requires only the same quantity of fuel to continue them at that temperature, whatever the size of the pipes may be: therefore, in those buildings in which the heat is constantly maintained, it is quite unimportant, on the score of economy, what is the size of the pipes; but in others, pipes of a moderately small size will be found more economical than large ones, and they should therefore be used in those cases where permanence of temperature is not a matter of importance.

204. The shape and size of the radiating surfaces, or vessels, also makes a material difference in the time requisite to warm a given space to any determinate temperature. The greater the surface, relatively to the mass, the more of its heat will the hot body part with in a given time. (Art. 70.) A

very great difference obtains in this respect, in different cases: for one body will cool three or four, or even eight or ten times as rapidly as another; and by sufficiently increasing the surface, in proportion to the mass, almost any degree of rapidity of heating a room or building may be attained. In many cases, however, this rapidity of heating is attended with considerable disadvantage; for the apparatus is then unable to retain its heat for a sufficient length of time, after the fire is extinguished.

205. In the preceding pages, all mention of the mechanical operation of fitting together the different parts of the apparatus, has purposely been avoided; neither is it here intended to enter into the subject. The necessary knowledge for this purpose is easily acquired by a good workman, even if he do not already possess it. The only part, therefore, which it is proposed to allude to, is the erroneous notion which some persons entertain respecting the joints of the pipes. That these require to be well made, there is no question; but to ensure their soundness or strength, it is by no means necessary, as some persons suppose, to use flange pipes: on the contrary, not only are socket pipes both neater, and less liable to leak, but it is doubtful whether they are not even stronger than flange joints. If the joints of the socket pipes be put together with iron cement, the pipe itself will break, before the faucet end of

the one pipe, can be drawn out of the socket of the other. In a hot-water apparatus, there is no expansive force employed which could, under any circumstances, force the pipes asunder; and, even for steam pipes, it is probable that, contrary to the usual practice, socket joints might be employed with advantage, and that economy and superior neatness, united with an equal degree of strength, would result from their use.

206. There are a great number of useful purposes to which this principle of heating is applicable, but to which it has hitherto been but sparingly applied, though it offers the promise of great utility. Such are the uses to which it may be adapted in various manufactories,—in paper-making, calico-printing, dyeing, and starch-making; and also for druggists, seedsmen, and innumerable other purposes of general utility. For many of these purposes it is exceedingly convenient, as the form of the heating surface can be made of any shape to suit the peculiar object [1] to which it is to be applied; and its equality of temperature prevents all those inconveniences

[1] One of the most ingenious applications of hot water that I have seen, is a kiln erected for Messrs. Keen, and Co. of Garlick Hill, Upper Thames Street. The whole floor of the kiln presents a surface which is warmed by the water circulating through it, and nothing appears which could reveal the method by which the heat is obtained. The saving is found to be very great, both in the preservation of the articles which are dried in it, and also by the great economy of fuel.

that arise from unequal degrees of heat, which are consequent on most other of the existing methods of warming.

207. All the rules which have been given in the previous pages, have been framed to suit the cases of most common occurrence. There are some cases, however, where apparatus of great magnitude are required, in which these rules will not apply without modification: but as such instances are of comparatively rare occurrence, and farther, as no person that is a novice in the practical application of this principle of warming, will be likely to undertake, for his first essay, the erection of an apparatus of gigantic dimensions, it is the less necessary to enter at length into such cases as it may be supposed will render any alteration of these principles necessary. It may, however, be observed, that cases may occur where a different construction of the boilers may be desirable, to that which has been recommended; for instance, where, from the large quantity of heat required, a furnace of very great power would be necessary; and in that case, a boiler which exposes a large surface, while it possesses only a small capacity, would obviously be injudicious, because the intense heat, acting on a small body of water, would, probably, generate steam of a high degree of elasticity in the boiler, and not only produce much inconvenience, but even neutralize the effect of what might otherwise be an efficient apparatus. Some

cases may occur, where two moderately small boilers will be more economical and effective than one very large one; and many cases may arise where several flow pipes, taken from different parts of a boiler, will be more advantageous than one large main pipe, particularly when the boiler is very large, or the water is required to circulate at different altitudes, varying considerably from each other. The size of the pipes also ought to be regulated, not only by the purpose to which the building is to be applied, but also to the quantity of pipe actually used in the building. For if the distance through which the water has to travel before it returns to the boiler, be very considerable, the size of the pipes ought not to be so small as to cause any very great degree of friction: neither ought they to be too large; because, in this case, the water will never reach so high a temperature as it otherwise would do, and therefore its effect will be proportionably less.

208. These remarks relate principally to the erection of the apparatus: others, however, may be added, which apply more to its practical working. One not unimportant subject, is the quality of the water which is used. Sometimes the foulest and most filthy water is used in a hot-water apparatus, by which a thick coating of mud is deposited, and which must, necessarily, not only much reduce the effect of the apparatus, but also injure the boiler. But a far more general, and in fact, an extremely

common error lies in using hard water, which contains a large quantity of earthy salts. Rain-water ought always to be used when it can possibly be obtained, because all hard waters are impregnated with saline matter, which forms the sediment, or incrustation, so common in those vessels in which water is boiled. This incrustation always accumulates in the boiler of a hot-water apparatus in which hard water is used, and forms a coating, varying in substance from the thinnest lamina, to two or three inches in thickness. When this deposit of saline matter occurs in a boiler, not only is less heat received by the water, in consequence of the conducting power being lessened by the interposed substance, but the boiler will be much injured by the increased heat of its external surface, and more fuel will be consumed.

209. This kind of sediment can only be removed from a boiler with great difficulty. It consists, principally, of carbonate of lime and sulphate of lime, together with the sulphates of soda and magnesia, and several other salts, varying considerably in different localities. A weak solution of muriatic acid (1 part of acid by measure to 20 or 30 parts of water) will generally reduce this concreted sediment, into a substance of less tenacity, which may then be removed with slight mechanical force. By using rain water, the inconvenience arising from these deposits will, however, be entirely avoided, and the apparatus will both last longer and be more efficient.

210. Some inconvenience has occasionally been experienced when a hot-water apparatus has been left for a long time without being used, and exposed to considerable degrees of cold, by the water becoming frozen in the pipes; for it is not only difficult in such cases to thaw the water, but sometimes also the pipes crack. To prevent this, it will generally be sufficient to draw off a portion of the water, so that the horizontal pipes shall not be quite full; for the cracking of the pipes arises from the sudden expansion which takes place in the water, at the moment of its passing into the solid state of ice. But when the apparatus is not likely to be used for a considerable time, it would be much better, if the weather be very cold, to empty the pipes entirely of water; for it is always troublesome to thaw the water when once frozen in the pipes. But in an apparatus used in a building of which the temperature is always above 32°, this is obviously unnecessary, as the water cannot then be frozen. A plan, however, might be adopted which would effectually prevent the water freezing with any ordinary degree of cold; namely, by using salt water in the apparatus, instead of fresh water. This plan would certainly be somewhat injurious to the apparatus, on account of the action of the salt on the iron; but the injury would not be at all extensive, and would be very slow in its operation. Perhaps in this country such a plan is unnecessary; but should this

kind of apparatus be adopted in colder climates, the suggestion might be useful. The larger the quantity of salt which a given portion of water contains, the greater is the degree of cold necessary to congeal it. Thus, the quantity of salt contained in sea water is about 3½ per cent.[1]; this requires, according to Dr. Marcet, a temperature of about 28° to freeze it: but if the quantity of salt be increased to 4·3 per cent., the water will not freeze until the cold be reduced to 27½° of Fahrenheit, or 4½° below the ordinary freezing point of fresh water. When the water contains 6·6 per cent. of salt, it will not freeze until the temperature be reduced to 25½ of Fahrenheit; and if it contains 11·1 per cent., the temperature must reach as low as 21½ before the water will congeal.

211. The effect which would be produced on cast-iron pipes and boilers, by any of these quantities of salt, would not be of much importance; although, in process of time, it would certainly, in some degree, corrode the apparatus[2]. When the apparatus has

[1] This quantity varies considerably in different localities. In the English Channel the quantity is as above stated; but on the coast of Spain it contains about 6 per cent., while the water of the Baltic only contains about 1½ per cent. Between the Tropics the quantity is very large;—as much as 10 per cent. is stated to exist in some of the tropical seas and oceans.

[2] A remarkable difference obtains in the rate at which oxydation acts on cast and on wrought iron. Hard cast iron will resist oxydation about three times as long as wrought iron; and, according to the experiments of Mr. Daniell, the same difference

been once filled with salt water, the waste which occurs in the water, by evaporation, should only be supplied with fresh water; for as the salt does not evaporate, the same quantity of salt will remain in the apparatus, and will combine with the fresh water when added.

212. As water can hold in solution as much as 35 per cent. of common salt (chloride of sodium), there is no fear of any deposit forming in the boiler from this cause. The reason of a deposit forming in boilers where hard water is used, is, because the water leaves behind, on evaporation, the saline compounds which it held in solution; and as the water which is added to supply the place of that which has evaporated likewise contains the same extraneous matter, the quantity presently becomes larger than the water can hold in solution, and the residue is precipitated and hardened by the heat of the fire. All the salts of lime, which are usually contained in hard water, are, likewise, soluble in this fluid only in a very limited degree. For instance, sulphate of lime, one of the most common ingredients in hard water, is soluble in it only to the extent of $\frac{1}{5}$ per cent., and carbonate of lime in a still smaller proportion; therefore the precipitation begins to take place as soon as the quantity exceeds this small amount.

exists in the length of time requisite to produce a given effect by acids. The effect on soft cast iron will approach nearer to that of wrought iron, varying with its hardness.

213. The necessity which exists for making sufficient provision for the expansion, both of the pipes and the water contained in them, has been mentioned in Chapter II.; and the requisite information respecting the sizes proper for the boilers, furnaces, main pipes, &c., has been given in Chapters III., IV., V. It, therefore, only remains to observe, that when these rules are followed, no doubts need be entertained, as to the successful and safe performance of any apparatus erected conformably to them: and, any one possessing an apparatus constructed on these principles, has, what should always be an object of paramount importance in such matters, a machine that requires no care nor attention, and of which the efficiency of performance for many years may be calculated on with certainty.

It may, however, be remarked, that many apparatus which have proved wholly abortive, as to any beneficial effect, have failed through the most trifling causes; so trifling, indeed, that it may safely be said, that alterations, which, if properly directed, would not, in some cases, have cost more than a few shillings in amount, would have converted the useless and unprofitable machine into a perfect and efficient apparatus. In many of these instances, the apparatus has been removed and destroyed, and the whole cost sacrificed; though, had the opinion of some scientific person been obtained, this waste and destruction of property might have been avoided.

CHAPTER XI.

ON VENTILATION.

Effects of Respiration, and the Chemical and Physical Alteration of the Air—Amount of Ventilation—Rules for Calculating the Proper Size for Ventilators—Different Methods of Producing Ventilation—Importance of Ventilation on Health.

214. No system of warming buildings, however good of itself, can be considered perfect without it is accompanied by sufficient ventilation. The best plan of artificial heat becomes inefficient without it; but with good ventilation, even the worst system of warming may be rendered tolerable.

215. Ventilation is a subject which has always attracted far less attention than it deserved. The general principles which are known, are seldom applied in a systematic manner. In small buildings it is in general wholly overlooked; and, in those of a larger description, where it becomes impossible entirely to neglect it, it generally fails in regard to quantity. In fact, the fundamental principles of ventilation are so simple, that almost the only diffi-

culty, except in some few extraordinary cases, is to apportion the proper amount, so that the ventilators shall be sufficiently large, without causing any unnecessary waste of heat. Some calculations on this subject may, therefore, perhaps, be useful.

216. In inhabited rooms, the quantity of air which is vitiated by the inmates varies considerably under different circumstances. When an individual is in a state of repose, the quantity of oxygen consumed, and the amount of vapour expulsed from the system, are much inferior to what they are when muscular exertion is used. It is, therefore, evident, that the ventilation of a manufactory, or of a ball room, ought to be much greater than is necessary for churches, lecture-rooms, concert-rooms, or any other building where the inmates are in a state of quietness and inactivity.

217. Lavoisier ascertained that the consumption of oxygen by a man, while engaged in strong muscular exertion, compared with the same individual while in a state of repose, was in the proportion of 32 to 14; and the quantity of vapour given off by the body, under different states of activity, is also found to vary in the same proportion.

218. The amount of the vapour which is discharged from the lungs, is variously stated by Menzies, Sanctorius, Abernethy, and Hales, at 6, 8, 9, and 20 ounces in 24 hours. The amount of perspiration from the skin, Keil found, by experiments made

upon himself, to be 31 ounces in 24 hours, or $10\frac{1}{2}$ grains per minute; but, according to Thenard, it varies from 9 to 26 grains per minute. The quantity of vapour thus given off from the system varies, however, not only under the different degrees of muscular exertion and repose, but also under the ever changing hygrometric condition of the atmosphere: for the greater the quantity of vapour which the air contains, the less will it be able to carry off from the human body. For the air possesses a desiccating power on the human body; but, of course, that power is lessened in proportion as it is nearer to the point of saturation.

219. The *hygrometric* condition of the atmosphere is ascertained by the *dew point*[1]. The lower is the dew point, the more moisture will be carried off from the lungs by the air, in respiration; and, therefore, less will be given off by perspiration, than when the dew point is higher. This is often the case in very cold weather, when a large quantity of vapour is carried off from the lungs, and but little

[1] The dew point is that thermometric temperature of the atmosphere at which vapour is condensed. By exposing a cold body to the air, a fine dew is deposited on its surface, and, by observing the temperature of this cold body, we know the exact quantity of vapour contained in the air at that time. Warm air contains a larger quantity of vapour than that which is colder; for air has the property of taking up water in solution in a quantity proportional to its temperature. The Table II. shows the quantity of vapour that the air contains when the dew point is obtained in this manner.

by perspiration. When air is respired from the lungs it is nearly of the temperature of the blood, which is 98° Fahrenheit; and it is then charged with a large quantity of vapour. If we ascertain the quantity of vapour which the air contains when expired, and deduct what it possessed before it was inhaled, we shall learn the amount given off by the lungs; the quantity of air breathed per minute being known. Now, suppose the temperature of the air, before it is inhaled, to be 40°, and the dew point 30°; as 800 cubic inches of air is the average quantity breathed per minute, $\frac{97}{100}$ of a grain[1] of vapour will be received into the lungs with the air, per minute. But when the air is again expired, the temperature will be about 95°, and the dew point probably about 85°: it will then contain 5·6 grains of vapour in the 800 cubic inches; so that upwards of 4½ grains per minute are given off from the lungs under these circumstances. But if the dew point of the air, before it is breathed, be 50°, which is frequently the case in damp or warm weather, then only 3½ grains of vapour will be given off in the same time. Dr. Dalton states, that in the torrid zone, the dew point sometimes rises to 80°, and that even in this country it occasionally reaches to 60°, while, in winter, it is sometimes below zero. This easily accounts for the variable quantity of moisture

[1] See Table II.

which is exhaled from the body and lungs at different times.

220. The atmosphere, during damp weather, when it is frequently nearly in a state of saturation, is unable to carry off the full quantity of vapour from the body. This causes the oppressive sensation that is so often experienced under such circumstances; and the slightest exertion causes the perspiration to condense upon the surface of the body, and a degree of heat is experienced, much greater than the simple thermometric temperature would occasion. This is often the case likewise in badly ventilated rooms. Here, however, another cause augments the inconvenience: for experiments have proved, that air, which has been once inhaled, lóses about 10 per cent. of its oxygen, or nearly one half that it contains, and acquires from 8 to $8\frac{1}{2}$ per cent. of carbonic acid gas. This gas, it is well known, is as destructive to animal life as the oxygen is necessary for its preservation, and, therefore, air cannot be breathed a second time without serious inconvenience. For, as it is found impossible to make atmospheric air contain more than 10 per cent. of carbonic acid gas, it follows, that, if breathing a quantity of air once, impregnates it with $8\frac{1}{2}$ per cent. of this gas, if it be breathed a second time, it can only receive $1\frac{1}{2}$ per cent.; and, therefore, the remainder must be left in the lungs, where it exerts a most deleterious effect. The noxious qualities of this gas are well known;

the foul air of wells, which causes death in so many instances, consists of this deleterious matter: and it is extraordinary that the heart and muscles of any animal that has been deprived of life by breathing it, entirely lose their irritability, and become insensible even to the powerful stimulus of galvanism.

221. Although the carbonic acid gas, given off from the lungs, is rather more than 37 per cent. heavier than the oxygen which is consumed, still, in consequence of the dilatation of its volume by the increased heat, and the greater levity of the vapour given off from the lungs, the air is specifically lighter at the moment of its expiration than at its inspiration. For 800 cubic inches of pure air at the temperature of 60°, and the dew point 40°, will weigh 243·395 grains; but 800 cubic inches of air at 95°, containing $8\frac{1}{2}$ per cent. of carbonic acid gas[1], and

[1] The quantity of carbon given off from the lungs being so considerable, we cannot wonder that the subject of its origin has been a deeply disputed question. Supposing 68 cubic inches of carbonic acid gas to be given off from the lungs per minute, on an average, that quantity will contain 8·63 grains of pure carbon, which in 24 hours will amount to 28 ounces. As this frequently exceeds the total quantity of food consumed in a day, it would seem impossible that the food were the only source which yields this substance: for, besides this, if the quantity of vapour from perspiration and pulmonary transpiration, be taken at 10 grains per minute for the former, and 3 grains for the latter, they will amount to 42 ounces in 24 hours, making the vapour and carbon together amount to nearly $4\frac{1}{2}$ lbs.; besides other excrementitious matter from the body. Some other source, then, besides the food, must exist for obtaining the matter which supports vitality, and this probably is the air. We have already seen that expired air,

5·6 grains of vapour, with the dew point 85°, will only weigh 232·450 grains, being nearly 5 per cent. lighter. Hence air, when expired from the lungs, always rises upwards, and will flow through ventilators in the ceiling, or the upper part of the walls of a room, if such be provided for its escape; but, otherwise, the vapour condenses, and the volume of the air collapses as it cools; it then becomes heavier than the substrata of air, and sinks to the lower part of the room contaminated with impurities.

is of less weight than the inspired, and it is probable that there is an absorption of it in the system to some considerable extent. It has been ascertained by Dr. Prout, that a vegetable diet diminishes the quantity of carbonic acid gas given off, and, of course, reduces the quantity of oxygen consumed; because carbonic acid gas contains exactly its own bulk of oxygen, united to the given weight of pure carbon. The accuracy of Dr. Prout's experiments has been confirmed by divers and persons making use of the diving bell. In all hot climates, also, where, from the rarified state of the air, less oxygen is received at each inspiration than in the higher latitudes, the inhabitants feel but little desire for animal food, and use, principally, a vegetable diet; while, on the contrary, the inhabitants of the Arctic regions use animal food almost exclusively. Dr. Richardson, who accompanied Capt. Franklyn on his voyage of discovery to the Polar seas, says, that himself and the other individuals, who composed the expedition, never felt the slightest wish for vegetable diet, but desired the most stimulating animal food, and in much larger quantities than they had ever before been accustomed to. In such a climate, in consequence of the coldness and density of the atmosphere, the quantity of oxygen inhaled is much greater than in warmer regions, and therefore allows the larger quantity of carbon to be carried off, which the dieting on animal food produces. These results, therefore, accord with Dr. Prout's experiments.

222. Such being the effects resulting from want of proper ventilation, it is necessary to inquire what is the quantity of air to be changed per minute, to maintain its purity in inhabited rooms and public buildings.

223. Although 800 cubic inches of air per minute, is a sufficient pulmonary supply for each individual, a much larger quantity is necessary to carry off the insensible perspiration. The amount of vapour from this cause, we have seen, has been variously stated by different experimentalists; but we may not, perhaps, be far wrong in estimating it, on an average, at 10 grains per minute, when the individual is not making any particular muscular exertions. If the temperature of a room be 60°, the air will absorb 5·7 grains of vapour per cubic foot; but, the average dew point being about 45°, the air will previously contain 3·5 grains; so that a cubic foot of air will only absorb an additional quantity of about $2\frac{1}{4}$ grains of vapour. Under these circumstances, the perspiration from the body will saturate $4\frac{1}{2}$ cubic feet of air per minute. But in estimating the quantity of air which is to be warmed, in order to allow of sufficient ventilation, this amount may be considerably reduced; because, as 45° is the average dew point for the whole year[1], it will be

[1] This is for the neighbourhood of London. It varies, of course, in different places, and is much influenced by the prevailing winds. An easterly wind travelling to us from the Conti-

much lower in winter and higher in summer, and, probably, will not exceed 20° or 25° on an average, during the time that artificial heat is required. Every cubic foot of air will then absorb an additional quantity of about $3\frac{1}{2}$ to 4 grains of vapour; and we may therefore estimate the quantity of air which is requisite to carry off the insensible perspiration, at 3 cubic feet, and for the pulmonary supply half a cubic foot per minute, for each individual.

224. This calculation is sufficient for estimating the quantity of air which in winter is required to be warmed per minute, as explained Art. 151. But for the purpose of summer ventilation a larger allowance should be made. As the dew point is much higher in summer, the air will absorb less moisture from the body, while at the same time, the exhalations from the body are considerably greater in summer than in winter. For summer ventilation, therefore, at least 5 cubic feet of air per minute, for each person, ought to be changed, in order to maintain the purity of the room; that is, $4\frac{1}{2}$ cubic feet

nent of Europe, and across the dry and arid countries of the Asiatic Continent, must necessarily part with much of its moisture, acquired from the Pacific Ocean, before it reaches us; and, therefore, it will be to us a dry wind: while, on the contrary, a westerly wind is always charged with a large quantity of moisture, absorbed during its passage from the American Continent, across the Atlantic. Its passage over this ocean,—a distance of 3000 miles,—occupies a period varying from 3 to 10 days; during which time it is constantly imbibing moisture from the ocean.

for the absorption of the insensible perspiration, and half a cubic foot for the pulmonary transpiration.

225. Other causes of deterioration of the quality of the air exist; such as the consumption of oxygen, and the elimination of extraneous gases, by the burning of fires, candles, lamps, &c.: but as all gases are capable of absorbing equal quantities of vapour, it follows that, when air has been deteriorated by these causes, so as to be less fit for respiration, it is still just as capable of carrying off the vapour from the surface of the body as pure air; and, therefore, no allowance needs be made for these causes of vitiation.

226. When the quantity of air has been ascertained which is necessary to be changed per minute in any inhabited room or building, the next thing is to estimate the proper size of the openings for the emission of the vitiated and foul air, and also for the admission of the fresh air which is required to supply its place.

227. When an opening is made in the ceiling or upper part of a room, the force which produces motion in the air is the same universal law which regulates the motion of falling bodies, and is precisely similar to the motion of water in a syphon,—which has been already explained. (Art. 32.) The total height from the floor of the room to the point of final escape of the heated air, is the height of the syphon. The force of motion is the difference of

weight between this column of heated air and that of a column of the external air of the same height. Now air expands, when heated, $\frac{1}{480}$ of its bulk for each degree of Fahrenheit; and the velocity of motion is equal to the additional height which a given weight of heated air must have, in order to balance the same weight of cold air. Thus, suppose a room 12 feet in height, and the air 20° higher in the room than the external temperature,—the air will expand $\frac{1}{24}$ of its bulk, by the excess of temperature: therefore, $12\frac{1}{2}$ feet of heated air will balance 12 feet of air which is 20° lower in temperature. It has already been explained (Art. 32), that, under such circumstances, the motion of fluids is equal to the velocity which a solid body would acquire, by falling through a space equal to the excess of height which the lighter body must have in order to balance the heavier: this velocity is *as the square root of* 16 *feet is to* 16 *feet per second, so is the square root of the given height to the velocity sought.* This resolves itself simply into multiplying the square root of 16 feet by the square root of the given height. But as the acquired velocity of a gravitating body is equal to twice the space it falls through in a given time (Art. 32), the number thus found must be doubled. In the case of the room we have before supposed, as the additional height of the heated column of air is 6 inches, so the square root of 6 inches, reduced to the decimal of a foot, multi-

plied by the square root of 16 feet, and that product multiplied by 2, will give 5·6 feet per second, as the velocity of the air. An opening in the ceiling, 1 foot square, will therefore discharge 336 cubic feet of air per minute.

228. It will be perceived that here also, as well as in the case of the circulation of water (Art. 33), if either the vertical height or the excess of temperature of the room be increased fourfold, the velocity will, in either case, be twice as rapid as before. But whatever be the calculated velocity, the real discharge will not be so great as this theoretical quantity,—not only in consequence of friction, but also because the air will be cooled in its passage through the ventilating tubes, particularly if they extend beyond the roof of the building. This will considerably lessen the discharge; and we ought therefore to deduct a certain amount from the calculation, which, on an average, should be about one fourth of the whole quantity.

229. The following Table will show the discharge *per minute* through a ventilator 1 foot square, for various heights and differences of temperature,—the allowance which is above stated having here been made. The discharge through a ventilator of any other size may easily be calculated; because, as the area is here 144 square inches, we have only to multiply the number of feet found by the Table, by the number of square inches in the area of the pro-

posed ventilator, and then, by dividing that number by 144, the quotient will be the quantity sought, which will represent the number of cubic feet of air that will be discharged per minute by the proposed ventilator.

TABLE of the Quantity of Air, in Cubic Feet, discharged per Minute, through a Ventilator of which the Area is 1 square Foot.

Height of Ventilator, in Feet.	Difference between Temperature of Room and External Air.					
	5°	10°	15°	20°	25°	30°
10	116	164	200	235	260	284
15	142	202	245	284	318	348
20	164	232	285	330	368	404
25	184	260	318	368	410	450
30	201	284	347	403	450	493
35	218	306	376	436	486	531
40	235	329	403	465	518	570
45	248	348	427	493	551	605
50	260	367	450	518	579	635

⁂ The above Table shows the discharge through a ventilator of any height, and for any difference of temperature. Thus, suppose the height of the ventilator, from the floor of the room to the extreme point of discharge, to be 30 feet, and the difference between the temperature of the room and of the external air to be 15°, then the discharge through a ventilator 1 foot square will be 347 cubic feet *per minute*. If the height be 40 feet, and the difference of temperature 20°, then the discharge will be 465 cubic feet *per minute*.

230. The height of the ventilator will, in some

cases, be very considerably greater than the height of the room. Suppose, for instance, a church is required to be ventilated; the ducts or channels which carry off the heated air will probably pass for a considerable height between the ceiling and the roof, and will, most likely, also extend above the roof. The total *vertical* height of all this must be measured as the height of the ventilator; but, of course, not taking into the account the lateral length which may be given to it for the purpose of uniting the several ventilators into one main trunk, or for making the extreme termination at a more convenient part of the roof.

231. As the discharge through any given height and size of ventilator, is less in proportion as the difference between the external and internal temperature is smaller, it follows, that it will be most difficult to obtain ventilation in hot weather. In summer, either the number or the dimensions of the ventilators should be increased; otherwise a room which is well ventilated in winter, will be extremely uncomfortable in summer. The increase in size can be effected by having moveable ventilators, which can be contracted at pleasure; and the actual size of the trunk or channel which conveys the air away, should be sufficiently large to carry off the largest quantity of air required for summer ventilation.

232. The openings for the admission of cold air, should always be placed as near to the floor as

possible. In size, they should be much larger than the area of the ventilators, in order that the influx of cold air may not proceed with too great velocity, and cause a draught. In fact, the size of these openings is a matter of indifference, provided only that they be sufficiently large; for the quantity of air which enters through them depends entirely upon the quantity that passes off through the ventilators, and not *vice versâ*: for if the passages for the cold air were double the size of the ventilators, no more cold air could enter, than a quantity equivalent to that of the heated air which escapes at the ceiling; and none of the heated air can escape at the cold air channels, because heated air cannot descend.

233. The more numerous and divided are the openings for the admission of cold air, the less inconvenience will be experienced by currents: but unless a sufficient quantity of cool air be admitted in this manner, there will be a counter current of cold air forced through the ventilators, which will descend and produce a very disagreeable draught.

234. In all moderate sized buildings, this mode of ventilation will be sufficient for every purpose. But in buildings of very great magnitude, artificial means of ventilation must be adopted, because the mere difference of weight between the two columns of air, will not be enough to expel the heated air with sufficient velocity, particularly in hot weather.

For theatres, this mode is generally inapplicable; and it has likewise been found ineffectual for the ventilation of the houses of Parliament.

235. The ventilation of the late House of Commons was, for many years, a subject of complaint, and it engaged the attention of many practical and scientific men. The apparatus which has recently been erected for this purpose, in the present House of Commons, under the direction of Dr. Reid, for producing ventilation by means of an immense chimney draught, appears to be a most expensive and cumbrous contrivance, for accomplishing an object obtainable by far easier means. The thorough ventilation of such a building as this, can only be procured by two methods,—draught by heat, or mechanical ventilation by a fan: but the latter of these methods possesses so many advantages over the former, that it appears surprising it should, for so many years, have been neglected; and that, of all the numerous plans which have been tried, for ventilating the late House of Commons, the draught by heat, though applied in various ways, has been the principle of them all. Dr. Ure has recently written a valuable memoir on the subject of ventilation, in which he compares the advantages of these two methods; and he estimates the economy of ventilating by a fan, compared with that by chimney draught, as about 38 to 1. In his calculations on this subject, however, he has apparently been led

into an error. His experiments on the consumption of fuel, to produce a given effect by chimney draught, were all made on furnaces used either for steam boilers, or for brewers' coppers. But, as it could only be the residual heat of the furnace which became available in his experiments, after the principal part of the heat given off by the coal had been absorbed by the boiler, it is certain that any calculation, founded on the effect produced in this manner, must be below the truth, as much probably as a half or two-thirds. But although the relative cost of fuel will not be so greatly different as Dr. Ure supposes, under any circumstances the difference between the two methods must be considerable.

236. The efficiency of the mechanical method of ventilation by a fan, turned by machinery, has been proved so extensively in some of the largest manufactories in the kingdom, that it appears singular Dr. Reid should have adopted so cumbrous and expensive a contrivance as that which he has erected at the present House of Commons. Whether or not this method of ventilation be adopted in the new Houses of Parliament, I have no doubt, that, ultimately, the more simple, efficient, and economical plan of ventilating by a fan will be resorted to.

237. As the motion of the air through tubes and ventilators depends for its velocity upon the vertical height of the tube only, it follows, that, if several

ventilating tubes be used in the same room, they must all be exactly of the same height; if they are not so, it frequently happens that cold air descends through the lower tubes, and the highest one alone conveys the heated air from the building. But the horizontal length of the tube, it has already been observed, makes no difference: and it is essential in large buildings, when more than one ventilator is necessary, either to connect the various lateral tubes into one main trunk, or else to have all the various tubes exactly of a similar altitude. Whether the heated air merely rises by its want of gravity, or whether it be drawn out of the building by means of a chimney draught, as adopted by Dr. Reid in the House of Commons, or exhausted mechanically by a fan, this rule, respecting the vertical height being the same in all the tubes, must be observed.

238. To conclude these remarks:—after what has here been stated, it were unnecessary farther to insist on the importance of ventilation, as regards both the health and comfort of all those whose occupations, or inclinations, confine them much within doors. The important alterations which atmospheric air undergoes in the process of breathing, would alone be sufficient to establish the necessity of attention to this subject. But the effects which arise from this cause, are often greatly increased by bad methods of warming: and these two causes combined, are sufficient to produce the most exten-

sive injury to the animal economy, when exposed to their influence for any length of time. In the following chapter, we shall endeavour, in following out this subject, to investigate the principles of the various methods of warming by artificial heat, and the physiological effects which result from their use.

CHAPTER XII.

On the different Modes of distributing Artificial Heat—Advantages of Radiating Heat at low Temperatures—Effects produced by Hot-Air Stoves in general—Nott's Stoves—Heating by Flues — Dr. Arnott's Stoves — Gas Stoves — General Remarks.

239. IMPORTANT as are the alterations which take place in atmospheric air by the process of respiration, not less important are those produced upon it by several of the methods now in use, for the warming of buildings; for the effects which result from many of them are highly injurious to animal life.

240. The effect produced on the animal economy by atmospheric air which has passed over intensely heated metallic surfaces, has already been noticed (Art. 183). There are, however, other changes produced on atmospheric air, by subjecting it to the action of heat, which are extremely important.

241. When air passes over the heated surface of a hot-air stove, the small particles of animal and vegetable matter, which are always held suspended

in the air, are decomposed by the heat, and resolved into their various elementary gases. This is one of the causes of the unpleasant smell which usually results from the use of such stoves. But in addition to this, the hygrometric water of the atmosphere is almost entirely decomposed; the oxygen entering into combination with the iron, and the hydrogen mixing with the air. This alteration materially affects the salubrity of the air: for not only is its desiccating influence on the lungs and skin increased to a most dangerous extent (Art. 218), but the admixture of the disengaged hydrogen with the atmospheric air, is, perhaps, even more injurious than the alteration of its hygrometric state; or, if not, its effects are, at all events, sooner discovered.

242. Signor Cardone made some experiments on the effects which result from the breathing of hydrogen gas. He inhaled 30 cubic inches, which is about one-ninth part the total capacity of the lungs; and the almost immediate effects he experienced were an oppressive difficulty of breathing, and painful constriction at the superior orifice of the stomach, followed by abundant perspiration, tremor of the body, heat, nausea, and violent headach; his vision became indistinct, and a deep murmur confused his hearing. Some of these symptoms lasted a considerable time, and were with difficulty got rid of.

243. The effects which are here described would

not, of course, be so powerfully experienced with the quantity of hydrogen that is disengaged by the action of a hot-air stove: but neither is this quantity so small as might be imagined, nor is it the sole cause of the injury which results from the use of such stoves.

244. We have already seen that the particles of animal and vegetable matter, contained in the air, are decomposed by the heat; and they then produce extraneous gases consisting of sulphuretted, phosphuretted, and carburetted hydrogen, with various compounds of nitrogen and carbon, all of which are of a character highly inimical to the animal economy. The quantity of hydrogen which is eliminated by the decomposition of the water contained in the air, is 1325 cubic inches for every cubic inch of water which is decomposed; and if the dew point of the air be 45° at an average, this quantity of gas will be given out from every 72 cubic feet of air which passes over the heated surface of the stove. It is, therefore, neither difficult to account for the enervating effects produced by hot-air stoves, in consequence of the air, when thus artificially dried, abstracting too much moisture from the human body, nor to foresee the injury which their constant use must produce, when used in close rooms, by breathing the extraneous gases which are evolved from the decomposition of the constituent parts of the atmosphere.

245. Though not usually susceptible of any diagnostic effects, I have, many times, felt sensibly affected on entering rooms heated by a peculiar kind of hot-air stove, which was invented by Dr. Nott. The extreme heat of these stoves, produces, in a very powerful degree, all the effects which are above described: and perhaps no better proof needs be desired, of the justice of the foregoing remarks, as applied to hot-air stoves in general, than can be obtained by any person standing near to one of these stoves for a few minutes. The feeling of oppression which is produced is intolerably painful; and the relief immediately experienced on going into the fresh air, at once points out the cause of the inconvenience.

246. The extreme dryness of the air, after it has been deprived of its hygrometric water by passing over a stove of this description, frequently produces violent headach[1]; and to remedy this evil it is usual to place a vase, containing water, on the stove, which, by yielding a portion of vapour to the air, attempers its extreme dryness, and in some degree mitigates this inconvenience. The evil, however, cannot be got rid of by such means; for even

[1] This is a necessary consequence of exposure to an atmosphere of excessive dryness: for the cold which is produced by the rapid evaporation of moisture from the skin, contracts the capacity of the absorbents, and causes the fluids to flow towards the head. Tension of the brain is thus produced, with all its attendant evils.

if the proper quantity of moisture could be again restored to the air, the effects which result from the evolution of extraneous gases, would not be at all removed.

247. As the power of iron to decompose water increases with the temperature of the iron, the limit to which the temperature of any metallic surfaces ought to be raised, which are used for radiating heat for the warming of buildings, should not much, if at all, exceed 212°, if the preservation of health is a matter of moment. The importance of this rule cannot be too strongly insisted on. It ought to be the fundamental principle of every plan: for upon it depends the wholesomeness of every system of artificial heat.

248. The various kinds of hot-air stoves, though they differ considerably in their effects, are all nearly similar in principle. In very large stoves, the air frequently passes over a surface of iron, nearly, if not quite, red hot, and is then conducted through pipes, or tubes, into different parts of the building which is to be warmed. This plan is perhaps the most unwholesome of all; because the surface over which the air passes is generally of a much higher temperature than in any of the other methods.

249. The heating by means of brick flues is nearly similar to the effect produced by hot-air stoves. The flues are usually of a very high tem-

perature, and always produce a most disagreeable and unwholesome smell by the decomposition of the floating particles of animal and vegetable matter contained in the air; and, probably, also, by the sublimation of a small portion of sulphur from the substance of the bricks themselves, as well as by the escape of various gases, generated during the combustion of the fuel, through either the joints or accidental fissures of the flues. The hygrometric water of the atmosphere, however, is not decomposed by this method of warming, because the materials of which the flues are composed have not an affinity for oxygen such as that possessed by heated metal: and in this particular flues are more wholesome than hot-air stoves.

250. A new kind of hot-air stove has lately been invented by Dr. Arnott, which is intended to obviate the bad effects resulting from those of the usual construction. This stove consists of an oblong case, or box, of wrought iron, about 3 feet long, 2 feet wide, and 2 feet high. It is divided across the middle by a partition which separates it into two distinct compartments, communicating with each other by small openings at top and bottom. The fire is contained in a fire-clay basket, which is placed in the first compartment, and the only air admitted is through a small circular hole at the side; the door in the front, for supplying fuel, being made to fit as close and as nearly air-tight as possible. A

metal cover, attached to a series of expanding plates, closes this hole: when the heat of the stove becomes too great, the plates, by their expansion, draw the cover, which closes the hole, inwards; thus shutting off the communication of the air, wholly or partially, according as the temperature acts with greater or less force on the expanding plates. On closing the opening in this manner, the fire immediately slackens for want of sufficient air to support combustion of the fuel; and the temperature of the stove decreasing, the plates inside again collapse, and thus admit more air to the fire: the combustion can therefore be regulated so as to keep the stove at almost any temperature. The air circulates within the two chambers by the small openings which connect them, but the room is warmed by the air passing over the surface of the stove only. The smoke escapes through a flue, in the usual manner; and as the fire never comes in contact with the surface of the stove, every part of it is kept at a low temperature,—about 200° of Fahrenheit.

251. The temperature of this stove being so low, no injurious effects are produced, as in other stoves, by decomposing the vapour and the particles of matter which are suspended in the air: but as a large quantity of carbonic oxide is generated by coke in a low state of combustion, there is a tendency for this deleterious gas to escape into the room, in consequence of the draught of the chimney being so

small, that it barely causes its withdrawal from the stove [1].

252. The heat afforded by this stove is so inconsiderable as to render it inapplicable, except in rooms of small size. The large dimensions of the stove is also an inconvenience; and if its size be reduced, the effect is also decreased in the same proportion, which must therefore prevent its use, except in a very limited degree.

253. The efficacy and advantages of any invention for warming, do not, however, simply consist in the fact, that the apparatus employed will not decompose the vapour contained in the atmosphere, or eliminate any permanently elastic gases; for if, on the contrary, a moist heat were produced, its influence on the human organization would be not less injurious than we have shown results from an opposite condition of the atmosphere.

254. As the air is only able to contain a definite quantity of vapour (Chapter XI.), by adopting any method of artificial heat which evolves an excess of

[1] This objection also lies against all stoves, which have a very slow draught. The effects produced by the breathing of this gas are extremely prejudicial to the animal economy. Sir H. Davy, on trying the effects of inhaling a small quantity of it, was seized with a temporary loss of sensation, succeeded by giddiness, sickness, and acute pains in different parts of his body; and it was some days before he entirely recovered. But Mr. Witter, of Dublin, who tried to repeat the experiments, was immediately affected with apoplexy, and was restored with difficulty.

moisture, the natural exhalations from the lungs and skin cannot be carried off, and pulmonary consumption must ultimately be induced, provided the continuance of the exciting cause be of sufficient duration. A notable instance of this kind of heat is that which is produced by the "gas stove," an invention by which the burning of carburetted hydrogen gas is employed as a substitute for coal. The effects of this plan are, however, very prejudicial to the human frame, for the whole of the gas consumed in these stoves is converted into two new compounds, water and carbonic acid gas,—which are both exhaled into the air of the room. The quantity of water, in the form of vapour, distributed by one of these stoves, is very considerable, for each cubic foot of carburetted hydrogen gas which is consumed, produces 2·6 cubic inches of water; and as the consumption of gas, in a moderate-sized stove of this description, is from 12 to 15 cubic feet per hour, the total quantity of water given off to the air, will be from a pint to a pint and a quarter per hour.

255. The large quantity of oxygen gas, which is abstracted from the air to support the flame of the carburetted hydrogen, would not of itself be of much consequence, provided the nitrogen, which is by this means set free, could escape, as it does in other stoves, without mixing with the air of the room. But, in consequence of these stoves having no flues,

the whole of the nitrogen or azotic gas[1], which is eliminated from the atmosphere, amounting to eight times the quantity of hydrogen consumed, or about 100 to 120 cubic feet per hour, together with about 12 or 15 cubic feet of carbonic acid gas, mixes with the air in the room, and must be breathed by the inmates, there being no outlet by which it can escape.

256. The plan which has recently been tried of introducing flues into these stoves, in order to carry off the unwholesome products of the combustion, would be a very great improvement, were it not that in carrying off the extraneous gases and the steam, the heat received in the room, is, at the same time, so much reduced, as to render the stoves comparatively valueless, as regards their heating effect. If the whole of the water, which is formed by a stove burning for 15 hours, at the rate of 15 cubic feet of gas per hour, escapes uncondensed in the state of steam, which is the form it assumes before it becomes water; as much heat will be carried off, as would, had the steam been condensed at the temperature of 60°, have heated 116,790 cubic feet of air 10°. To this must be added, the loss from the heated air that escapes through the flue, which is probably about as much more; and, together, the

[1] The name of *azote* (derived from two Greek words, signifying *without life*,) was given to this gas, on account of its peculiarly fatal effects on animal life.

amount thus lost is nearly one-half the heat which the stove affords under the most favourable circumstances. This may be proved by the following calculation, showing at the same time, the relative cost of warming by gas and by coal.

257. The experiments of Dr. Dalton have proved that by the combustion of one pound in weight of carburetted hydrogen gas, as much heat is generated as will melt 85 lbs. of ice. Now, a cubic foot of carburetted hydrogen weighs 292·89 grains, and, in a stove burning 15 cubic feet an hour, for 15 hours a day, there will be 225 cubic feet, or 9·41 lbs. of gas consumed, which would, therefore, melt 799 lbs. of ice; and the cost of this quantity of gas, at the usual average price, would be two shillings and threepence. The latent heat of water being 140°, it requires as much heat to melt 1 lb. of ice, and to raise its temperature from 32° to 33°, as would raise the temperature of the same weight of water 141°; and as the cubic foot of water weighs 62·33 lbs., therefore, the same quantity of heat that would melt 799 lbs. of ice would heat 12·8 cubic feet of water 140°, or 179.2 cubic feet 10°. By referring to Art. 140, we shall find that 1 cubic foot of water will raise the temperature of 2990 cubic feet of air as many degrees as the water loses; and the combustion of 225 cubic feet of carburetted hydrogen gas would therefore raise the temperature of 535,808 cubic feet of air 10°. The quantity of coal which will produce the

same effect is easily ascertained. By Art. 138, we find that 1 lb. of coal will heat 39 lbs. of water 180°, or 702 lbs. of water 10°. This is equal to 11,170 lbs., or 179·20 cubic feet of water being heated 10° by 15·91 lbs. of coal: and this number of cubic feet of water multiplied by 2990 (Art. 140), will give 535,808 cubic feet, as the quantity of air that would be heated 10° by 15·91 lbs. of coal, which is exactly the same result as is obtained by the combustion of 225 cubic feet of carburetted hydrogen gas. The only difference would be that the gas would cost 2*s.* 3*d.*, and the coal no more than 3*d.*, or, to allow for extra expenditure of fuel, from imperfect construction of the stove, say the coal will cost 5*d.*; so that a gas stove, without a flue, will cost about five times as much for fuel, as a hot-air stove which burns coal, and about ten times as much as coal, if the gas stove has a flue[1].

258. It requires no deep researches into the principles of physiology, to appreciate, in some degree, at least, the merits of a method of artificial heat, which is free from all the noxious effects which we have seen result from the use of most of the inventions that have been described. Although many persons

[1] This latter amount may be reduced by making the flue of the stove very long and very large in diameter, so as to condense the steam by exposing to it a large surface. This would save a considerable portion of heat, but the form and size of the flue would probably be very inconvenient.

are not aware of the full extent of the injury that results from these causes, the merest sciolist in the investigation of natural phenomena must acknowledge, that the more we deviate from the simplicity of Nature's laws, the more fatal are the effects on that most delicate of all her works—organic life. And it needs no farther arguments to prove that it must be injurious to breathe an atmosphere contaminated by extraneous gases, which have not the power of supporting animal life, or that extracting from the air its natural humidity, or, on the contrary, loading it with vast quantities of moisture, must produce consequences inimical to the health of organized beings.

259. Nor is it only to animal life that these results ensue. It is equally on all departments of organized existence, in the vegetable as well as the animal kingdom, that the injurious effects of erroneous principles of warming exert their influence; for it will readily be conceded that we cannot violate the one class of laws with impunity, any more than we can the other. It is therefore only conformable to what might be anticipated, that practical gardeners have almost universally acknowledged the superior healthiness and productiveness of plants cultivated in houses which are warmed by the circulation of hot water.

260. The perfect freedom from all these noxious effects which have been described, is not the least

important of the advantages afforded by this method of distributing artificial heat. It would, however, be attended with disadvantages of a formidable character, if it were applied to any inhabited rooms which are not supplied with proper ventilation. In a room warmed by stoves of the common construction, the open fire-place itself affords sufficient ventilation in ordinary cases; but with all other modes of warming, ventilation must be supplied, if it be wished to avoid the evils resulting to the human frame, from breathing a vitiated atmosphere, whether it be rendered impure by having passed through the lungs, or in consequence of extraneous gases either generated or evolved by peculiar methods of warming.

261. This remark would have been superfluous, were it not that cases have occurred where the evils that have arisen from defective ventilation have been erroneously attributed to this plan of warming by hot water; and the vapour which is given off from the lungs of the inmates of a room, and, under these circumstances, is condensed upon the windows, has been supposed to arise from the water in the apparatus being converted into steam, and escaping through the joints of the pipes. If this were a solitary opinion, it might, like many others equally erroneous, merely excite a smile from those who are better acquainted with the subject; but as this has been seriously objected against the invention, by

many who ought to know better, it may be worth while to state the cause more at length.

262. The quantity of vapour given off from the lungs, and also by exhalation from the skin, has been estimated at from 12 to 13 grains per minute. If, in consequence of imperfect ventilation of inhabited rooms, the air cannot escape after it has received this additional quantity of vapour exhaled from the body, it must, as soon as it has acquired a larger quantity of moisture than the temperature of the *external* air will support in the form of vapour (Art. 219), deposit a portion of it upon the glass; because, the glass being nearly of the same temperature as the external air, whatever quantity of the internal air comes in contact with it, its temperature is immediately lowered, and the excess of its vapour is condensed upon the surface of the glass. Thus, suppose the temperature of the air in a room to be 65°, and the dew point 55°, then, if the temperature of the external air be only 35°, as much of the air in the room as comes in contact with the glass, will deposit whatever vapour it contains above the quantity that a temperature of 35° will enable it to sustain. Under these circumstances, the amount deposited on the glass will be (Art. 219) about 2 grains for each cubic foot of air that is cooled by the glass; and the same effect, though in a less degree, will take place on all the other cold surfaces in the room. As each square foot of glass will cool

one and a quarter cubic feet of air per minute, from the internal to the external temperature (Art. 145), we shall find that, under the circumstances we have supposed,—which is purposely taken as an extreme case,—the quantity of vapour deposited in this manner will amount to $2\frac{1}{2}$ grains per minute, on each square foot of glass.

263. We need be at no loss, then, to discover the cause of this accumulation of vapour on the windows and walls of rooms which are badly ventilated; and whenever the quantity of moisture thus condensed appears to be considerable, it may be taken as good evidence that the ventilation of the room is imperfect. That the same effect does not result from the use of hot-air stoves, is in consequence of the vapour being decomposed by the intense heat; but when this method of avoiding the inconvenience is adopted, a worse evil is produced than that which is attempted to be removed, although, perhaps, it is not so obvious to the sight.

264. Some of the preceding remarks have extended to a greater length, and have assumed a more prominent place, than was intended; but it may not, perhaps, be deemed altogether superfluous, in concluding this Treatise, to observe, that the investigation of the physiological effects of the different systems of artificial heat, is not only interesting in a scientific point of view to the physiologist, but it closely concerns almost every individual

member of the community. It is a question which affects not merely the personal comfort of individuals, but, according to the opinion of some of our ablest pathologists, it influences the health, and even affects the duration of life. Such a subject, then, cannot but be deserving of investigation: and if these observations, imperfect as they are, have the effect of directing more general attention to the inquiry, they will not have been made in vain.

TABLE I.

TABLE of the Expansive Force of Steam, in Atmospheres, and in lbs. per square inch; for temperatures above 212° of Fahrenheit.

N.B. The steam is supposed to be in contact with the water from which it is formed, and the water and steam to be alike in temperature.

Heat in Degrees of Fahrenheit.	Pressure.		Heat in Degrees of Fahrenheit.	Pressure.		Heat in Degrees of Fahrenheit.	Pressure.	
	Atmospheres.	lbs.		Atmospheres.	lbs.		Atmospheres.	lbs.
212	1	15	431	23	345	646	150	2250
251	2	30	436	24	360	655	160	2400
275	3	45	439	25	375	663	170	2550
294	4	60	457	30	450	671	180	2700
308	5	75	473	35	525	679	190	2850
320	6	90	487	40	600	686	200	3000
332	7	105	499	45	675	694	210	3150
342	8	120	511	50	750	700	220	3300
351	9	135	521	55	825	707	230	3450
359	10	150	531	60	900	713	240	3600
367	11	165	540	65	975	719	250	3750
374	12	180	549	70	1050	726	260	3900
381	13	195	557	75	1125	731	270	4050
387	14	210	565	80	1200	737	280	4200
393	15	225	572	85	1275	742	290	4350
399	16	240	579	90	1350	748	300	4500
404	17	255	586	95	1425	753	310	4650
409	18	270	592	100	1500	758	320	4800
414	19	285	605	110	1650	763	330	4950
418	20	300	616	120	1800	768	340	5100
423	21	315	627	130	1950	772	350	5250
427	22	330	636	140	2100			

⁂ The above Table is deduced from the experiments of M. M. Dulong and Arago. Their calculations extend only as far as 50 atmospheres; from thence the pressures are now calculated to 350 atmospheres by their formula, viz.:—

$$t = \frac{\sqrt[5]{e} - 1}{\cdot 7153}$$

where e represents the pressure in atmospheres, and t the tem-

perature above 100° of Centigrade. In this equation each 100° of Centigrade is represented by unity.

In reducing these temperatures from Centigrade to Fahrenheit's scale, where the fractions amount to ·5, they have been taken as the next degree above, and all fractions below ·5 have been rejected.

TABLE II.

TABLE of the Quantity of Vapour contained in Atmospheric Air, at different Temperatures, when saturated.

Temperature of Air.	Quantity of Vapour per Cubic Foot: in Grains Weight.	Temperature of Air.	Quantity of Vapour per Cubic Foot: in Grains Weight.	Temperature of Air.	Quantity of Vapour per Cubic Foot: in Grains Weight.
20°	1·52	48°	3·98	76°	9·53
22	1·64	50	4·24	78	10·16
24	1·76	52	4·52	80	10·78
26	1·90	54	4·82	82	11·49
28	2·03	56	5·13	84	12·20
30	2·25	58	5·51	86	12·91
32	2·32	60	5·83	88	13·61
34	2·48	62	6·21	90	14·42
36	2·64	64	6·60	92	15·22
38	2·82	66	7·00	94	16·11
40	3·02	68	7·43	96	17·11
42	3·24	70	7·90	98	18·20
44	3·48	72	8·40	100	19·39
46	3·73	74	8·95		

_ The above Table is computed from Dr. Dalton's Experiments on the Elastic Force of Vapour.

TABLE III.

TABLE of the Expansion of Air and other Gases by Heat, when perfectly free from Vapour.

Temperature, Fahrenheit's Scale.	Expansion.	Temperature, Fahrenheit's Scale.	Expansion.
32°	1000	100°	1152
35	1007	110	1178
40	1021	120	1194
45	1032	130	1215
50	1043	140	1235
55	1055	150	1255
60	1066	160	1275
65	1077	170	1295
70	1089	180	1315
75	1099	190	1334
80	1110	200	1354
85	1121	210	1372
90	1132	212	1376
95	1142		

⁎ The above numbers are obtained from Dr. Dalton's experiments, which give an average of $\frac{1}{483}$ part, or ·00207 for the expansion by each degree of Fahrenheit. Gay Lussac found it to be equal to $\frac{1}{480}$ part, or ·002083 for each degree of Fahrenheit; and that the same law extends to condensable vapours when excluded from contact of the liquids which produce them.

TABLE IV.

TABLE of the Specific Gravity and Expansion of Water at different Temperatures.

Temperature, Fahrenheit's Scale.	Expansion.	Specific Gravity.	Weight of 1 Cubic Inch, in Grains.	Temperature, Fahrenheit's Scale.	Expansion.	Specific Gravity.	Weight of 1 Cubic Inch, in Grains.
30°	·00017	·9998	252·714	121°	·01236	·9878	249·677
32	·00010	·9999	252·734	124	·01319	·9870	249·473
34	·00005	·9999	252·745	127	·01403	·9861	249·265
36	·00004	·9999	252·753	130	·01490	·9853	249·053
38	·000002	·9999	252·758	133	·01578	·9844	248·836
39	·00000	1·0000	252·759	136	·01668	·9836	248·615
43	·00003	·9999	252·750	139	·01760	·9827	248·391
46	·00010	·9999	252·734	142	·01853	·9818	248·163
49	·00021	·9997	252·704	145	·01947	·9809	247·931
52	·00036	·9996	252·667	148	·02043	·9799	247 697
55	·00054	·9994	252·621	151	·02141	·9790	247·459
58	·00076	·9992	252·566	154	·02240	·9780	247·219
61	·00101	·9989	252·502	157	·02340	·9771	246·976
64	·00130	·9986	252·429	160	·02441	·9760	246·707
67	·00163	·9983	252·349	163	·02543	·9751	246·483
70	·00198	·9981	252·285	166	·02647	·9741	246·233
73	·00237	·9976	252·162	169	·02751	·9731	245 982
76	·00278	·9972	252·058	172	·02856	·9721	245·729
79	·00323	·9967	251·945	175	·02962	·9711	245·474
82	·00371	·9963	251·825	178	·03068	·9701	245·218
85	·00422	·9958	251·698	181	·03176	·9691	244·962
88	·00476	·9952	251·564	184	·03284	·9681	244 704
91	·00533	·9947	251·422	187	·03392	·9671	244·446
94	.00592	·9941	251·275	190	·03501	·9660	244·187
97	·00654	·9935	251·121	193	·03610	·9650	243·928
100	·00718	·9928	250·960	196	·03720	·9640	243·669
103	·00785	·9922	250·794	199	·03829	·9630	243·410
106	·00855	·9915	250·621	202	·03939	·9619	243·151
109	·00927	·9908	250·443	205	·04049	·9609	242·893
112	·01001	·9901	250·259	208	·04159	·9599	242·635
115	·01077	·9893	250·070	212	·04306	·9585	242·293
118	·01156	·9885	249·876				

⁂ In the above Table the expansions are calculated by Dr. Young's formula, $22f^2\ (1-\cdot002f)$ in 10 millionths. The diminution of specific gravity is calculated by this equation: $\cdot0000022f^2 - \cdot00000000472f^3$. In both equations, f represents the number of degrees above or below 39° of Fahrenheit. The absolute weight of a cubic inch of water, at any temperature, may be found by multiplying the weight of a cubic inch at 39°, by the specific gravity at the required temperature.

TABLE V.

TABLE of the Specific Heat, Specific Gravity, and Expansion by Heat of different Bodies.

Barometer 30 Inches.—Thermometer 60°.

	Specific Heat.			Weight of 100 Cubic Inches.	
	Of equal Weights, by Berard and Delaroche.	Of equal Volumes, by Petit and Dulong.	Specific Gravity.	Barometer 30 Inches. Thermometer 60°.	Linear Expansion by 180° of Heat, from 32° to 212°.
				Grains.	
Air (atmospheric)	·2669	..	1·000	30·519	
— (dry) .... *Apjohn*	·2767	..	..	...	
Aqueous vapour	·8470	..	·633	19·321*	
Azote	·2754	..	·9722	29·65	
—— oxide of	·2369	..	1·5277	46·596	
Carbonic acid	·2210	..	1·5277	46·596	
——— oxide	·2884	..	·9722	29·65	
Hydrogen	3·2936	..	·0694	2·118	
Olefiant gas	·4207	..	·9722	29·65	
Oxygen	·2361	..	1·1111	33·888	
Water	1·000	..			
				Ounces.	
Water	..	1·000	1·000	57·87	
Bismuth	..	·0288	9·880	571·7	
Brass	..	..	7·824	452·77	·00186671 = $\frac{1}{535}$
—— wire	..	..	8·396	485·87	·00193000 = $\frac{1}{518}$
Cobalt	..	·1498	8·600	497·6	....
Copper	..	·0949	8·900	515·0	·00172244 = $\frac{1}{581}$
Gold	..	·0298	19·250	1114·0	·00146606 = $\frac{1}{682}$
Glass (flint)	..	..	2·760	159·72	·00081166 = $\frac{1}{1248}$
—— (tube)	..	..	2·520	145·83	·00087572 = $\frac{1}{1142}$
Iron (cast)	..	..	7·248	418·9	·00111111 = $\frac{1}{900}$
—— (bar)	..	·1100	7·788	450·2	·00122045 = $\frac{1}{819}$
Lead	..	·0293	11·350	656·8	·00284836 = $\frac{1}{351}$
Nickel	..	·1035	8·279	478·5	....
Pewter (fine)	..	..	..	..	·00228300 = $\frac{1}{438}$
Platinum	..	·0314	21·470	1242·4	·00099180 = $\frac{1}{1008}$
Silver	..	·0557	10·470	605·8	.00208260 = $\frac{1}{480}$
Solder (lead 2 + tin 1) .	..	..	..	..	·00250800 = $\frac{1}{398}$
Spelter (brass 2 + zinc 1)	..	..	..	..	·00205800 = $\frac{1}{486}$
Steel (untempered) ...	..	..	7·840	453·7	·00107875 = $\frac{1}{927}$
—— (yellow tempered)	..	..	7·816	452·31	·00136900 = $\frac{1}{730}$
Sulphur	.	·1880	1·990	115·1	....
Tellurium	..	·0912	6·115	353·5	....
Tin	..	·0514	7·291	421·9	·00217298 = $\frac{1}{462}$
Zinc	..	·0927	7·191	416·0	·00294200 = $\frac{1}{339}$

*** Air is taken as the standard for the specific gravity of the gases, and water as the standard for the solids.

* Specific gravity of steam at 212° = ·481. Weight of 100 cubic inches, 14·680 grains.

TABLE VI.

TABLE of the Effects of Heat.

	Wedgwood's Scale.	Fahrenheit's Scale.
Greatest heat observed	185	25127
Hessian crucible fused	150	20557
Cast iron thoroughly melted . . .	150	20577
Greatest heat of a smith's forge . . .	125	17327
Ditto of a plate-glass furnace .	124	17197
Ditto of a flint glass ditto . .	114	15897
Derby porcelain vitrifies	112	15637
Welding heat of iron (greatest) . . .	95	13427
Ditto ditto (least)	90	12777
Fine gold melts	32	5237
Fine silver melts	28	4717
Swedish copper melts	27	4587
Brass melts	21	3807
Diamond burns	14	2897
Red heat fully visible in day light . .	1	1077
Iron red-hot in the twilight		884
Charcoal burns		802
Heat of a common fire		790
Iron bright-red in the dark		752
Zinc melts (680° Davy)		700
Mercury boils (Black 600°) (Secondat 644°) (Petit and Dulong)		656
———(Crichton 655°)(Irvine 672°) (Dalton)		660
Lowest ignition of iron in the dark		635
Lead melts (Guyton and Irvine 594°) (Crichton) .		612
Steel becomes dark blue, verging on black . . .		600
Ditto a full blue		560
Sulphur burns		560
Steel becomes bright blue		550
Ditto purple		530
Ditto brown, with purple spots		510
Ditto brown		490
Bismuth melts		476
Steel becomes a full yellow		470
Ditto a pale straw colour		450
Tin melts		442
Steel becomes very faint yellow . . . . . , .		430
Tin 3 + lead 2 + bismuth 1, melts		334
Tin and bismuth, equal parts, melts		283
Bismuth 5 + tin 3 + lead 2, melts		212

Table of the Effects of Heat (*continued*).

	Fahrenheit's Scale.
Water boils (barometer 30 in.)	212
Water freezes	32
Milk freezes	30
Vinegar freezes	28
Sea water freezes	28
Strong wine freezes	20
Quicksilver congeals	—39
Sulphuric æther congeals	—47
Natural temperature at Hudson's Bay	—51
Great artificial cold	—91

TABLE VII.

TABLE of the Quantity of Water contained in 100 Feet of Pipe, of different diameters.

Diameter of Pipe.	Contents of 100 Feet in length.
Inches.	Gallons.
½	·84
1	3·39
1½	7·64
2	13·58
2½	21·22
3	30·56
4	54·33
5	84·90
6	122·26

TABLE VIII.

TABLE of the Strength, or Cohesive Force, of different Substances: By GEO. RENNIE.

Bars of 6 inches long and a ¼ of an inch square will break with the following weights suspended lengthways:—

	lbs.
Cast Iron (horizontal)	1166
Ditto (vertical)	1218
Cast Steel (tilted)	8391
Blistered Steel (hammered)	8322
Shear Steel (ditto)	7977
Swedish Iron	4504
English Iron	3492
Hard Gun-metal	2273
Wrought Copper (hammered)	2112
Cast Copper	1192
Fine Yellow Brass	1123
Cast Tin	296
Cast Lead	114

⁎ A round bar of best English Iron, one-inch diameter, when subjected to a longitudinal strain, will break with a weight of 43,520 lbs., or rather less than 19½ tons. This agrees very nearly with the amount above stated.

TABLE of the Relative Cohesive Strength of Metals: By SICKENGER.

Gold	150,955
Silver	190,771
Platinum	262,361
Copper	304,696
Soft Iron	362,927
Hard Iron	559,880

INDEX.

THE END.

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